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COST AND PERFORMANCE MODELS FOR ELECTROSTATICALLY STIMULATED FABRIC FILTRATION

by

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16. ABSTRACT The report gives results of a survey of the literature on performance models for pulse-cleaned fabric filters. Each model is evaluated for its ability to predict average pressure drop from pilot plant data. The best model is chosen and used, in conjunction with pressure drop reduction data from an electrostatically stimulated fabric filter (ESFF) pilot plant, to produce a model of ESFF performance. The accuracy of the models is limited by their primitive nature and the size of the pulse-jet performance data base. Where the baghouse, dust, and fabric to be modeled are very similar to the pilot plant from which the model was developed, the model should perform adequately for comparison between ESFF and non-ESFF baghouses. Published correlations relating equipment size and cost are used in a model for predicting the capital and operating costs of conventional pulse-jet baghouses. A comparison between predicted capital costs and independently obtained estimates shows that the baghouse model is capable of + or - 20% accuracy. A prototype design for ESFF hardware is developed, and cost quotes from vendors are incorporated into a predictive equation for ESFF costs. Because there are no pulse-jet ESFF baghouses, the prototype design is subject to revision, a lack of certainty that restricts the accuracy of ESFF cost predictions to + or - 30% accuracy.

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Filtration	Computer Programs	Stationary Sources	07D	
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ABSTRACT

A survey of the literature on performance models for pulse-cleaned fabric filters is presented. Each performance model is evaluated for its ability to predict average pressure drop from pilot plant data. The best model is chosen and used in conjunction with pressure drop reduction data from an electrostatically stimulated fabric filter (ESFF) pilot plant to produce a model of ESFF performance. The accuracy of the performance models is limited by their primitive nature and the size of the pulse-jet performance data base. For those cases where the baghouse, dust, and fabric to be modeled are very similar to the pilot plant from which the model was developed, the model should perform adequately for comparison between ESFF and non-ESFF baghouses.

Published correlations relating equipment size and cost are used in a model for predicting the capital and operating costs of conventional pulse-jet baghouses. A comparison between predicted capital costs and independently obtained estimates shows that the baghouse cost model is capable of ±20% accuracy. A prototype design for ESFF hardware is developed and cost quotes obtained from vendors are incorporated into a predictive equation for ESFF costs. In view of the fact that there are no existing pulse-jet ESFF baghouses, the prototype design is subject to revision. This lack of certainty in the hardware design restricts the accuracy of ESFF cost predictions to ±30. The cost model is best used in comparing cost estimates of ESFF and non-ESFF pulse-jet baghouses and in comparisons of different sizes of conventional pulse-jet baghouses.

The performance and cost models are incorporated into a computer program for two different computers: the Tektronix series 4050 computers and the TRS-80 Model I and III microcomputers. The program requires pulse-jet design data as input and predicts average pressure drop, capital cost, operating cost, and net present value. Complete program documentation is also included.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A_j	cross-sectional area of pulse-jet nozzle
A_n	net cloth area for flow
A_p	uniform annual payment
b_n	cumulative uniform series factor
C_{in}	dust concentration at inlet to filter
CT_{ash}	annual cost of electricity for ash conveying
CT_b	capital cost of pulse-jet baghouse
CT_{con}	capital cost of ash conveyor
CT_{damp}	capital cost of inlet/outlet dampers
CT_{duct}	capital cost of ducting
CT_{fab}	unit cost of fabric
CT_{fan}	annual cost of electricity for induced draft fan
CT_{fms}	capital cost of fan, motor, and starter
CT_{ins}	capital cost of baghouse insulation
CT_{kWh}	unit cost of electricity
$CT_{m/m}$	annual cost of maintenance, labor, and materials
CT_{OL}	annual cost of operating labor
CT_{pond}	capital cost of ash pond
CT_{pulse}	annual cost of electricity for compressed air
CT_{rep}	annual cost of bag replacement
ESFF	electrostatic stimulation of fabric filtration
f	electric field applied to filter

ABBREVIATIONS

FPA	Fundamental Planning Analysis
I	capital investment
K	proportionality constant in Darcy's law
K_1, K_3, K_4	constants used in the Leith and Ellenbecker model
K_2	specific resistance coefficient based on P_e
K_2'	specific resistance coefficient based on P_r
L	length of filter bed
L_c	length of ash conveyor
mlr	maintenance labor rate
NPV	net present value
n	number of years over which annual payments are made
N	number of bags in the baghouse
OHF	fractional cost increment for overhead
olr	operating labor rate
P	pressure drop across filter
P_e	effective residual pressure drop
P_j	pulse-air reservoir pressure
P_{max}	maximum pressure drop across filter
P_r	actual residual pressure drop
P_s	maximum static pressure
PDR	pressure drop ratio
PR	reverse pressure drop
ΔP_{ave}	average pressure drop across filter
Q	flue gas flow rate

ABBREVIATIONS

R	effective annual discount rate
r	fractional reduction in residual pressure drop
S	drag across filter
S_e	effective residual drag across filter
S_r	actual residual drag across filter
SIR	savings/investment ratio
SPV	present value of annual cost savings
t	time since cleaning of filter
T	temperature
TR	transformer-rectifier
V	air velocity
W	areal dust loading on filter

SYMBOLS

α	fraction of dust removed from filter during cleaning pulse
β	fraction of that dust removed from filter, α, during the cleaning pulse that falls to hopper and is removed from the system
ε	fraction of inlet dust removed from system per cycle
ρ	bulk gas density

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CHAPTER 1

SUMMARY

1.1 INTRODUCTION

Electrostatic stimulation of fabric filtration (ESFF) is the technique of applying an electric field to the surface of a fabric filter to enhance the collection of particulate matter. An added benefit of ESFF is a reduction of the pressure drop across the filter. This technology has been successfully demonstrated on a pilot scale pulse-jet fabric filter by VanOsdell et al.[1] They have shown from preliminary estimates that this technology may also be economically feasible.[1] This report documents a computer program that can be used to evaluate the costs of both conventional and electrically enhanced, pulse-jet, baghouse filters to aid in deciding when to apply this new technology. The computer program contains modules that will model the performance and the cost-estimating aspects for the pulse-jet filter. Descriptions of these modules, a listing of the computer program, and user documentation are included in this report.

Chapter 2 discusses the pulse-jet performance model including descriptions of the ESFF data found by VanOsdell et al.[1] Current models available in the literature for conventional pulse-jet filters are presented in Appendix A. Chapter 3 details the economic measures of merit that are applied both to new units and to old units that are retrofitted with new equipment. Chapter 4 details the equations used to estimate the capital and operating costs of pulse-jet baghouses with and without ESFF hardware. The final chapter of the report gives instructions for using the computer program (listed in Appendix B) to calculate the performance and costs.

1.2 CONCLUSIONS

Performance models for conventional as well as electrostatically stimulated fabric filtration in pulse-jet cleaned fabric filters have not been rigorously developed or tested. A simplified model based on user input of key parameters for the conventional pulse-jet system and on key

parameters from the ESFF study of VanOsdell et al.[1] has been developed in order to give a rough prediction of the pulse-jet performance.

A model for predicting the capital and operating costs of pulse-jet baghouses with and without ESFF enhancement has been developed. The model predicts the cost of the major equipment items based on net cloth area and gas flow rate. The installation costs and associated indirect costs are calculated using Lang factors. Based on a comparison with independently developed cost estimates, the model appears to be capable of predicting capital costs with ±20 percent accuracy. Based on what is known about the equipment design and operational requirements, it is expected that predictions of ESFF hardware costs and operation and maintenance costs should have an accuracy of ±30%.

1.3 RECOMMENDATIONS

- Models such as those suggested in Appendix A for conventional (i.e., non-ESFF) pulse-jet baghouses should be developed further. The effects of cleaning characteristics, such as maximum static pressure in the bag and the pressure rise time on baghouse pressure drop, should be investigated. Further understanding of the conventional pulse jet, especially with regard to residual dust loading, should facilitate understanding of the ESFF effect.

- Further investigation of the ESFF effect is needed. The effects of different types of fly ash, fabrics, and variations in applied voltage on baghouse pressure drop need to be investigated.

- The accuracy of all capital and operating cost modeling equations should be verified by comparison with costs from an operating baghouse.

- The assumed prototype for ESFF hardware needs further development. When actual design data become available, the cost model should be modified to reflect the updated design. When cost data from an ESFF baghouse become available, the cost modeling equation should be verified.

CHAPTER 2

PERFORMANCE MODEL

Design of a pulse-jet fabric filter requires predicting the maximum and average pressure drops for the filter and for the gas flow through the entire system, and determining the maximum penetration of particles and agglomerates through the filter. Prediction of the cost of a fabric filter is usually more sensitive to the pressure drop calculations since the collection efficiency is generally greater than 99 percent.[2 3] Thus for the performance model in this cost analysis only the pressure drop will be considered.

The state of the theoretical and empirical models for predicting pressure drops in conventional pulse-jet fabric filters is not well developed. The empirical models are limited to the conditions under which they were developed. The theoretical, or quasitheoretical, models have not been well tested for conditions other than those used by their authors; furthermore, they require some data for determining unknown constants. Thus it is necessary to rely primarily on full-scale plant and pilot-plant experience for designing new systems.

The approach currently used for modeling electrostatically enhanced fabric filters requires knowledge of the conventional, nonenhanced filters and of the effect of the electric field on the ratio of the pressure drop of the ESFF to that of the conventional filter.[1 3 4] Current ESFF research has not led to other quantitative methods for predicting pressure drop improvements due to ESFF. At present, the ESFF concept has not been tested on a large scale (i.e., on the order of 3,000 m^3/min). Of the pilot-plant studies reported in the literature, that of VanOsdell et al.[1] is the most applicable for this study since the pilot unit was operated continuously over long periods of time using a slip stream from an industrial boiler.

Therefore, the pressure drop performance model used in this cost analysis will rely on user experience for the conventional pulse-jet data and on the operating experience of VanOsdell et al.[1] for the ESFF data. This section describes the performance model and explains why this approach was used.

Fabric filtration theory has been reviewed by Billings and Wilder.[5] The major assumptions used for modeling fabric filters will be presented briefly to describe the approach taken in the ESFF performance analysis.

Conventional fabric filtration theory is based on the Darcy's law assumption that the pressure drop across a packed bed of solids is proportional to the velocity and bed length for viscous flow at low Reynolds numbers. One form of Darcy's law is thus

$$P = KVL \tag{1}$$

where P = pressure drop across the bed
L = bed length or dust thickness
K = constant--dependent on bed structure and fluid properties
V = velocity.

For fabric filtration, the experimental data are usually gathered as pressure drop versus time curves as shown in Figure 2-1. For fabric filters, in contrast to deep bed filters or packed beds, the length of the bed changes as the dust is deposited on the fabric surface; therefore, the pressure drop must be related to the cake buildup on the fabric. It is assumed that during a given unit of time a constant amount of dust is deposited on the filter and that the structure of this dust deposit does not change as more dust is deposited. Thus the surface loading W, mass/area, increases linearly as the dust thickness increases. Thus from Equation 1

$$P = K_2VW \tag{2}$$

where $W = C_{in}\,Vt$; the loading on the filter, W, equals the inlet dust concentration, C_{in} (mass/volume), that has entered in time, t, with velocity V. K_2 is the specific dust-fabric filter resistance coefficient.

However, the pressure drop across the filter is not strictly a linear function of time and thus the effect of cleaning needs to be considered in Equation 2. Figure 2-1 shows that a well-conditioned fabric operating at

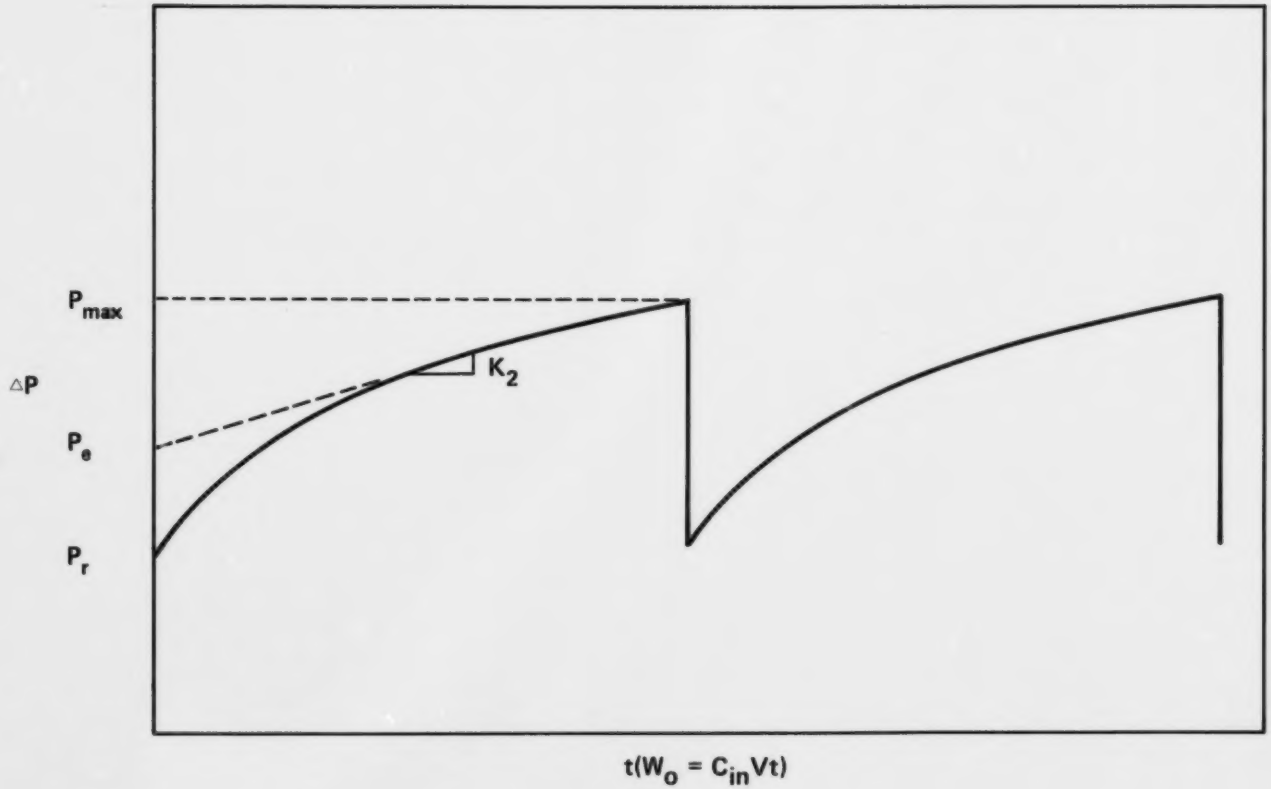


Figure 2-1. Pressure drop versus cycle time for pulse-jet fabric filters.

steady state has a residual pressure drop, P_r, caused by the dust that is not cleaned from the fabric. The nonlinear behavior is not predicted by Equation 2, and it is often assumed for fabric filters that the behavior can be described in terms of an effective residual pressure drop, P_e, the intercept of the curve of pressure as a function of time as shown in Figure 2-1. This equation is

$$P = P_e + K_2VW \ . \tag{3}$$

In order to remove the effect of face velocity, it is often useful to define the drag as $S = P/V$. This gives

$$S = S_e + K_2W \ . \tag{4}$$

Billings[5] notes that S_e is some function of S_r ($= P_r/V$), the fabric, and the dust type.

Thus, in order to design a conventional fabric filter for a given set of inlet conditions, including inlet dust concentration, velocity, and cycle time, either (1) P_e (S_e) and K_2 or (2) P_r (S_r) and the nonlinear behavior of P (S) with loading must be predicted. Current pulse-jet theories will be discussed briefly in Appendix A to illustrate the problems with the available correlations for predicting these parameters. Since there are no good theories for predicting these parameters, the computer program will require the input of values of these parameters.

To extend the conventional pulse-jet to the ESFF pulse-jet, one must predict the change in these parameters with the applied field. Since there are little data available to predict these effects, rough approximations must be made based on the available data.

Experimental data from ESFF units are reported in terms of the pressure drop ratio (PDR) defined as

$$PDR = (P_{max} - P_r)_{ESFF}/(P_{max} - P_r)_{conventional} \tag{5}$$

Where P_{max} is the maximum pressure (see Figure 2-1) that is reached in one cycle of filtration. If PDR is known as a function of applied voltage and

$(P_{max} - P_r)$ conventional is known, then $(P_{max} - P_r)_{ESFF}$ can be calculated. To find $(P_{max})_{ESFF}$ the $(P_r)_{ESFF}$ must be known.

Pilot plant experience indicates that P_r varies with time as the fabric is conditioned during startup and in the final phase as the bag is worn out. No attempt is made to account for this; steady state is assumed. It is also expected that P_r and therefore P_e are functions of the cleaning intensity. No attempt has been made in the literature to predict P_r as a function of cleaning efficiency or other operating parameters, but Dennis and Klemm[6] and Dennis et al.[7] attempt to predict P_e as a function of the reservoir pressure of the cleaning pulse and several other operating parameters. Their work was with coal fly ash filtered with wool and polyester felts. It was tested on a very limited amount of data, and thus it is not recommended until further experimental work confirms their findings.

VanOsdell et al.[1] found that P_r is significantly affected by the ESFF, but they reported no clear trends or correlations with applied field voltage, face velocity, or cleaning cycle duration because of scatter in their data and limited parameter testing. They found an average reduction in residual pressure drop of 0.42 with a standard deviation of 0.27 for a wide range of operating conditions. The reduction in residual pressure drop is defined as

$$r = (P_r \text{ conventional} - P_r \text{ ESFF})/P_r \text{ conventional} . \qquad (6)$$

For want of further information, the model for this program shall use a reduction in residual pressure drop of 0.42 when comparing the ESFF to the conventional pulse jet. Thus given r and $(P_r)_{conventional}$, then $(P_r)_{ESFF}$ can be predicted from Equation 6 and thus $(P_{max})_{ESFF}$ from Equation 5 can be found.

Dennis and Klemm[6] and Dennis et al.[7] assume that the K_2 for pulse-jet filters can be approximated by the K_2 found for reverse air. For ideal Darcy's filtration, K_2 should depend only upon the dust cake structure and not on the method of cleaning. However, pulse-jet filters may affect the deposited dust in two ways that are different from the reverse-air filters. First, pulse-jet filters use nonwoven fabrics and thus the dust deposited within the fabric and the dust/fabric interface may be significantly different from the woven fabrics used in reverse air. The second difference

arises from the dust that is redeposited on the filter after the cleaning pulse is completed; this dust may have been agglomerated and its cake structure thereby altered due to the forces of cleaning. Additionally, even if the K_2 from the reverse air could be used for pulse-jets, the K_2 correlations that Dennis et al. propose are based on meager data and no information is available for K_2.

Dennis and Klemm[6] found that K_2 may be affected by the face velocity. They found, based on meager data for coal fly ash, that they could adjust K_2 from one velocity to another by

$$(K_2)_2 = (K_2)_1 \ (V_1/V_2)^{\frac{1}{2}} \tag{7}$$

This relationship was used in this analysis to compare the K_2 for the conventional at one velocity, with that at other velocities.

The K_2 values found in the control unit of the VanOsdell et al.[1] work varied from 1.9 to 9.2 N-min/g-m.

Figure 2-2 gives a plot of the PDR versus the applied field data found by VanOsdell et al.[1] These data were empirically fit to give

$$PDR = 0.77 \exp(-.25f) \quad 5 > f \geq 0.75 \tag{8}$$

$$PDR = 1.0-.63f + .21f^2 - .024f^3 \quad f < 0.75 \tag{9}$$

where

$$PDR = (P - P_r)_{ESFF}/(P - P_r)_{conventional} \tag{10}$$

and f is the applied field in KV/cm. VanOsdell et al.[1] show optimum PDR at field voltages between 2.5 and 3.0 kV/cm. Operation at applied fields greater than this would not result in much better performance. This work is based on dust from an industrial coal boiler filtered with Teflon fabric bags. PDR results were not affected by face velocity over the range (1.5 to 4.0 cm/s) studied at the pilot plant. PDR calculations for this cost analysis program are based on these equations. The effect of glass woven fabric was found to increase the PDR. The effect of other fabrics is not known.

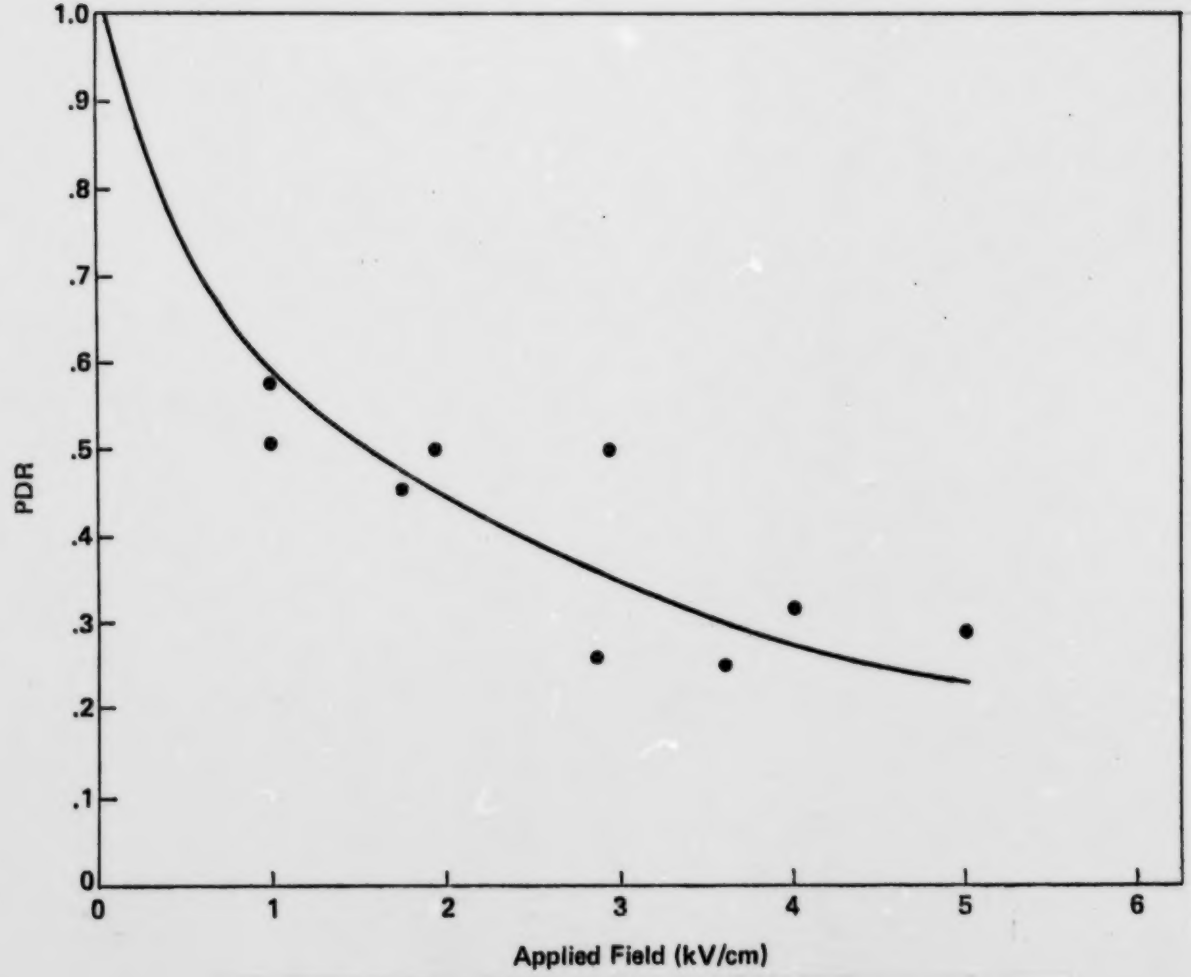


Figure 2-2. PDR versus applied field for data from VanOsdell et al.[1] Smooth curve from Equations 9 to 11.

Table 2-1 lists the input options provided in the program. If values of S_r, S_e, and K_2 are available for the dust/fabric unit of interest, they should be used as a first choice. If a set of data on P vs. W is available, Equation 3 will be used to calculate K_2.

Thus, it is clear that not much is known or quantified about pulse-jet filters and about ESFF applied to pulse-jet filters. Appendix A describes the empirical and theoretical models for conventional pulse-jet filters that are available in the literature to illustrate some of the parameters and variables that need to be considered to further develop pulse-jet models. However, before application of the models described in Appendix A can be made, more information is needed to test them for different conditions and to test the assumptions more rigorously. Therefore, because of the lack of well-tested models, a simple approach based on conventional fabric filtration theory and pilot-plant experimental data is applied in this study. Table 2-1 summarizes the equations used in the computer program.

TABLE 2-1. PERFORMANCE MODEL

Input:

Option #1--$P_r(S_r)$ $P_e(S_e)$, C_{in}, t, V, K_2, applied field

Option #2--Data set of P_{max}, $P_r(S_r)$ $P_e(S_e)$, C_{in}, t, V, applied field f; the program will calculate $K_2=(P_{max}-P_e)/((C_{in}Vt)V)$

Pressure drop calculation:

(1) $W = C_{in}Vt$

(2) (P_{max}) conventional $= S_eV + K_2\ VW$

(3) $(P_r)_{ESFF} = (P_r)$ conventional $(1-r)$, $r=0.42$, $P_r=S_r \cdot V$

(4) PDR = f(applied field), by Equations 8-10

(5) $(P_{max})_{ESFF} = P_r$ ESFF + $((P_{max})_{conventional} - P_r) \times$ PDR

(6) P_{ave} ESFF = $((P_{max})$ ESFF + P_r ESFF$)/2$

Output:

$(P_{max})_{ESFF}$, $(P_{ave})_{ESFF}$, PDR, $(P_r)_{ESFF}$, K_2

CHAPTER 3

ECONOMIC ANALYSIS AND MEASURES OF MERIT

It is widely recognized that careful and systematic methods are necessary for the proper evaluation and reporting of the economic feasibility of a proposed project. Both the EPA and the Navy have published standard methods[8] [9] for this type of analysis and both contain essentially the same elements. They include:

1. Defining the objective
2. Generating alternatives
3. Formulating assumptions
4. Determining costs and benefits
5. Comparing costs and benefits and rank alternatives
6. Performing sensitivity analyses.[9]

These guidelines will be followed throughout the following discussion of economic analysis, and the two methods[8] [9] will be compared and shown to be essentially the same.

The objective of the pollution control system for this study is to meet State and EPA requirements for particulate emissions from coal-fired boilers. In the case of an existing pollution control device, the objective may be to reduce emissions and/or to reduce operating costs.

The purpose of this report is to determine how well a new pulse-jet baghouse or a pulse-jet baghouse retrofitted with FSFF hardware can meet these objectives. By no means do these alternatives represent the only available systems for particulate control; however, they are the only systems to be considered here. It is up to the reader to identify and evaluate the economic feasibility of other alternatives.

The third step in an economic analysis is the formulation of assumptions. This step is similar to the Descriptive Segment and Specified Parameters discussed by Uhl.[8] It is assumed for the plant that the boiler is of the pulverized-coal type and that the fly ash has properties similar to the fly ash encountered by VanOsdell et al.[1] at the Waynesboro plant and in the laboratory. It is further assumed, with respect to economic factors, that no lead time is required, regardless of baghouse size; the equipment will be bought outright (i.e., there are no capital recovery costs); there is a ready supply of civilian labor available for construction and operation of the baghouse; no changes in plant working capital are required; there are no existing assets that can be employed in or replaced by construction of a new or retrofitted baghouse; the life of an existing baghouse is not changed by retrofitting it with ESFF hardware; the fly ash collected in the baghouse has no value; and finally, the terminal value of the baghouse or retrofit hardware is offset exactly by the cost of removing the equipment. Assumptions specific to the equipment used in the baghouse will be discussed in Chapter 4.

A measure of merit describes the economic feasibility of a project. For the purposes of the Navy, the evaluation of a baghouse falls under the category of a Fundamental Planning Analysis (FPA). A project to retrofit a baghouse with ESFF hardware to reduce its pressure drop and therefore lower the operating costs requires a Type I FPA. The construction of a new baghouse, either with or without ESFF, requires a Type II FPA. A Type I FPA results in a value of the Savings/Investment Ratio (SIR), which is similar to the Return on Investment indicator discussed by Uhl.[8] Another measure of merit that can be used to describe a Type I FPA is the payback period. This quantity is also recognized by Uhl.[8] Either of these measures of merit (SIR or payback period) can be used to determine the economic feasibility of a project under both Navy and EPA guidelines.

The measure of merit that characterizes a Type II FPA is the equivalent uniform annual cost. For this study, the other particulate control alternatives are unknown and therefore it may not always be possible to calculate the equivalent annual cost. It is possible to calculate the Net Present Value (NPV), which can then be used to determine the equivalent

annual cost when alternatives are formulated. Therefore the NPV will be the result of the Type II FPA reported by the computer program.

A rigorous evaluation of a project's measure of merit would incorporate the effects of depreciation, tax credits, inflation, and other indirect costs on the annual payment. The consideration of these factors is beyond the scope of this project, though it is still desired to estimate the appropriate measures of merit. Therefore, in the computer programs described in Chapter 5, the reported measures of merit are based on the capital cost and the operation and maintenance costs only. As such, the reported values represent "before-tax" estimates of the measures of merit. For those who wish to pursue a more rigorous evaluation of the measure of merit, the capital cost and operation and maintenance costs are also reported.

In the following sections the three measures of merit--SIR, payback period, and NPV--are described and example calculations are given.

3.1 CALCULATION OF SAVINGS/INVESTMENT RATIO

The Savings/Investment Ratio gives a direct measure of the "profitability" of a proposed modification in current operations. Before the savings gained by retrofitting a baghouse with ESFF are calculated, the annual operating and maintenance (O&M) costs for the ESFF baghouse must be computed. This amount is then subtracted from the current annual O&M costs to determine the annual savings in current dollars. This difference must be positive if ESFF is to offer any economic advantage over the status quo. Before determining the economic benefit of an ESFF retrofit over the remaining life of the baghouse, the cumulative savings must be computed by use of the cumulative uniform series factor. This factor discounts the value of money that is to be paid out in the future to the value at the present time. This factor is calculated as:

$$b_n = \frac{\exp(n \cdot \ln(1+R)) - 1}{\ln(1+R) \cdot \exp(n \cdot \ln(1+R))} \qquad (11)$$

where

n = the number of years the annual payments are to be made

R = the effective annual discount rate.

The present value of a series of uniform annual payments is then calculated as:

$$SPV = A_p b_n \qquad (12)$$

where

A_p = the uniform annual payment.

The SIR is then computed as the ratio of the present value of the annual savings to the investment cost of retrofitting the baghouse with ESFF hardware.

For example, assume a retrofit project required one-time costs of $50,000 and thereafter provided an annual savings of $7,000 over the remaining 10 years in the life of the baghouse. The present value of the savings that would be realized over the 10-year period is:

$$SPV = 7{,}000 \cdot \frac{\exp(10 \cdot \ln(1+0.1)) - 1}{\ln(1+0.1) \cdot \exp(10 \cdot \ln(1+0.1))}$$

$$= 7{,}000 \cdot 6.447$$

$$= \$45{,}128 .$$

It has been assumed here that the effective annual discount rate (R) is 10 percent. The savings/investment ratio is thus

$$SIR = \frac{\$45{,}128}{50{,}000} = 0.902 .$$

This result indicates that in this case the retrofit project would not be advantageous.

3.2 CALCULATION OF PAYBACK PERIOD

According to the Navy's "Economic Analysis Handbook,"[9] the "discounted payback occurs when the present value of accumulated savings equals the present value of the investment." Mathematically this can be expressed as:

$$\text{Payback period} = \frac{-\ln(1 - \ln(1+R) \cdot I/A_p)}{\ln(1+R)} \qquad (13)$$

where

I = the amount invested

A_p = the uniform annual payment in current dollars

R = the effective annual discount rate.

Here it has been assumed that there is no lead time involved in realizing the benefits of the ESFF retrofit.

The payback period can be used in an interesting way to evaluate the example from the previous section. Using equation 13 the payback period can be calculated as:

$$\text{Payback period} = \frac{-\ln\left(1-\ln(1+0.1) \cdot \frac{50,000}{7,000}\right)}{\ln(1+0.1)}$$

$$= 12 \text{ years} .$$

This result can be interpreted to mean that the investment in retrofit equipment would break even after 12 years of operation and return a profit, so to speak, after the 12th year.

3.3 CALCULATION OF NET PRESENT VALUE

The net present value is the sum of the present values of the annual costs for each year of equipment life. It is assumed that the payment schedule for capital and operating costs is on an annual basis and that the project requires no lead time. If the annual cost is constant, as is assumed here, the net present value of the annual payments can be calculated from the cumulative uniform series factor defined in Section 3.1. The capital cost must be added to the annual cost to determine the total NPV. It has been assumed that there will be no capital recovery costs associated with the purchase of the equipment. In other words, the equipment will be purchased outright with no financing. As an example of an NPV calculation, consider a plant which costs \$100,000 to purchase and install and requires \$10,000 each year for operating and maintenance. The NPV of this plant for N = 12 years is:

$$NPV = \$100,000 + \$10,000 \cdot \frac{\exp(12 \cdot \ln(1+0.1)) - 1}{\ln(1+0.1) \cdot \exp(12 \cdot \ln(1+0.1))}$$

$$= \$100,000 + \$10,000 \cdot 7.149$$

$$= \$171,490$$

where it has been assumed that R = 0.1. If it were necessary to finance the equipment purchase, then the annual financing cost would have to be included in the NPV.

Before any measures of merit can be calculated, it is necessary to determine the capital and operating costs. In Section 4 the equations for predicting the cost of pulse-jet baghouses, both with and without ESFF, are described in detail. Equations for estimating annual operating and maintenance costs are also described.

CHAPTER 4

PULSE-JET BAGHOUSE COST ESTIMATION

4.1 INTRODUCTION

Each of the measures of merit discussed in the previous section requires knowledge of the initial investment in equipment and the annual cost of operating the equipment. The initial investment is the capital cost of the project which includes the cost of purchasing and installing the baghouse system. The annual cost consists of the yearly operating and maintenance costs as well as the capital recovery costs. The estimation of these costs is the subject of this section.

Neveril[10] presents a complete method for estimating the capital and operating costs for pulse-jet baghouses. His method is used here and will be reviewed in detail in this section.

The capital cost of a large project is typically broken into two categories: direct costs and indirect costs. The direct cost is further divided into purchased equipment costs and installation costs as shown in Table 4-1. For any project, the cost of the baghouse, ESFF hardware (if necessary), auxiliary equipment, controls, taxes, and freight are included within the purchased equipment cost subcategory. The installation cost includes such items as foundations and supports, electrical work, piping, etc., as needed for the baghouse installation. The indirect costs include engineering, construction and field expenses, construction fee, startup, performance testing, and contingencies. The sum of the direct and indirect costs is the capital cost.

The estimation of the capital cost proceeds as follows:

1. The costs of the baghouse, insulation, ducting, fan, ash conveyor, and ash pond are estimated or obtained from vendor quotes.

2. The sum of these costs is multiplied by a set of factors to include the costs of instrumentation and controls, taxes,

and freight. The sum of these quantities is the purchased equipment cost.

3. The installation cost is obtained by multiplying the purchased equipment cost by a set of factors to account for the various items required for installation.

4. The sum of the purchased equipment cost and the installation costs is the direct cost.

5. The indirect cost is obtained by multiplying the purchased equipment cost by a set of factors to account for the various items in this category.

6. The sum of the direct and indirect costs is the capital cost of the project. This procedure will be illustrated in an example at the end of this section.

The cost factors listed in Table 4-1 for estimation of instrumentation, freight, installation, and indirect costs are values for typical systems. That is, the plant is assumed to be of moderate size and relatively easy to get to; the site poses no difficulties--i.e., adequate room, no blasting required; and the process is well established (this is not a good assumption for an ESFF baghouse). Oftentimes these assumptions will be invalid and the use of the factors in Table 4-1 would yield cost estimates that are too high or too low. Consequently, it is often necessary to adjust these cost factors. Neveril[10] has presented guidelines for making the necessary adjustments and these are presented in Table 4-2. The use of these adjustment factors will be presented in the example at the end of this section.

Operating costs can be estimated based on the size of the baghouse and/or the gas flow rate through the baghouse. These costs include operating labor and material, maintenance labor and material, overhead, property tax, insurance, administration, and capital recovery cost as shown in Table 4-3. The labor and materials costs are estimated directly from the size of the equipment, the labor rate, and the material costs. The overhead cost is computed as a fraction of the sum of the operating and maintenance labor and materials costs. The annual costs of property tax, insurance, and administration are estimated as fractions of the capital cost. The capital recovery cost is calculated from the capital cost, interest rate, and expected life of the equipment.

TABLE 4-1. ESTIMATION OF CAPITAL COSTS

Direct Costs	Typical Cost Factor
Purchased Equipment Costs	
Baghouse	As per Equation 14
ESFF hardware	As per Equation 25
Auxiliary equipment	As per Equations 15-24
Instruments and controls	0.10
Taxes	0.03
Freight	0.03
Installation Costs	
Foundation and supports	0.04
Erection and handling	0.50
Electrical	0.08
Piping	0.01
Insulation	0.07
Painting	0.02
Site preparation	0.01
Facilities and buildings	0.02
Indirect Costs	
Engineering and supervision	0.10
Construction and field expenses	0.20
Construction fee	0.10
Startup	0.01
Performance test	0.01
Contingencies	0.03
Capital cost = direct costs + indirect costs	

TABLE 4-2. COST ADJUSTMENT FACTORS

	Cost adjustment
A. Instrumentation	
1. Simple, continuous manually operated	0.5 to 1.0
2. Intermittent operation, modulating flow with emissions monitoring instrumentation	1.0 to 1.5
3. Hazardous operation with explosive gases and safety backups	3
B. Freight	
1. Major metropolitan areas in continental United States	0.2 to 1.0
2. Remote areas in continental United States	1.5
3. Alaska, Hawaii, and foreign countries	2
C. Handling and Erection	
1. Assembly included in delivered cost with supports, base, skids included. Small- to moderate-size equipment	0.2 to 0.5
2. Equipment supplied in modules, compact area site with ducts and piping less than 200 ft in length. Moderate size system	1
3. Large system, scattered equipment with long runs. Equipment requires fabrication at site with extensive welding and erection	1 to 1.5
4. Retrofit of existing system; includes removal of existing equipment and renovation of site. Moderate to large system	2
D. Site Preparation	
1. Within battery limits of existing plant; includes minimum effort to clear, grub, and level	0
2. Outside battery limits; extensive leveling and removal of existing structures; includes land survey and study	1

(continued)

TABLE 4-2 (continued)

	Cost adjustment
3. Requires extensive excavation and land ballast and leveling. May require dewatering and pilings	2
E. Facilities and Buildings	
1. Outdoor units, utilities at site	0
2. Outdoor units with some weather enclosures. Requires utilities brought to site, access roads, fencing, and minimum lighting	1
3. Requires building with heating and cooling, sanitation facilities, with shops and office. May include railroad sidings, truck depot, with parking area	2
F. Engineering and Supervision	
1. Small capacity standard equipment, duplication of typical system, turnkey quote	0.5
2. Custom equipment, automated controls	1 to 2
3. New process or prototype equipment, large system	3
G. Construction and Field Expenses	
1. Small capacity systems	.5
2. Medium capacity systems	1
3. Large capacity systems	1.5
H. Construction Fee	
1. Turnkey project, erection and installation included in equipment cost	.5
2. Single contractor for total installation	1
3. Multiple contractors with A&E firm's supervision	2

(continued)

TABLE 4-2 (continued)

		Cost adjustment
I.	Contingency	
	1. Firm process	1
	2. Prototype or experimental process subject to change	3 to 5
	3. Guarantee of efficiencies and operating specifications requiring initial pilot tests, deferment of payment until final certification of EPA tests, penalty for failure to meet completion date or efficiency	5 to 10

TABLE 4-3. ANNUAL OPERATING EXPENSES

Direct Operating Costs	
Operating labor	
Operator	As per Equation 26
Supervisor	As per Equation 26
Operating material (bags)	As per Equation 28
Maintenance	
Labor	As per Equation 27
Material	As per Equation 27
Utilities	
Compressed air	As per Equation 29
Electricity	As per Equations 30-32
Indirect Operating Costs	
Overhead	80% of (operating labor and material plus maintenance)
Property tax	1% of capital cost
Insurance	1% of capital cost
Administration	2% of capital cost
Capital recovery cost	As per Equation 33

In the subsections below, equations for estimating the capital cost of a pulse-jet baghouse, ducting, ash removal system, fan, and ash pond will be described. The ESFF hardware, if required, would be included with the cost of these items in the purchased equipment cost but for the sake of clarity the description of ESFF hardware costs will be described separately. The estimation of operating and maintenance costs will also be described. At the end of this section, a comprehensive example illustrating the use of all of these factors will be presented.

4.2 CAPITAL EQUIPMENT

The cost of a carbon steel, shop-assembled, continuous-duty pulse-jet baghouse can be estimated from the equation

$$CT_b = 5{,}370 + 81.8 \cdot A_n \qquad (14)$$

where

CT_b = the cost of the baghouse

A_n = the net cloth area for flow in square meters.

Similarly, the cost of insulation for the baghouse is calculated as

$$CT_{ins} = 4{,}910 + 25.8\ A_n\ . \qquad (15)$$

The cost for 15.2 m (50 ft) of 3/16-in ducting to the baghouse is calculated based on flow rate (Q) by

$$CT_{duct} = 15.2 \cdot (-5.77 + 177 \cdot 1.128 \cdot 0.2562 \cdot Q^{\frac{1}{2}}) \qquad (16)$$

where the flow rate has units of actual cubic meters per second. Inherent in this equation is an assumed flow rate of 15.3 m/s (3,000 ft/min), which is typical for flue gases. The costs of the inlet/outlet dampers are estimated as

$$CT_{damp} = 1{,}100 + 64.8 \cdot Q \qquad (17)$$

and the cost of a backward curved fan capable of delivering a 50-cm (20-in) H_2O static pressure with motor and starter is estimated as

$$CT_{fms} = 2{,}600 + 528.5 \cdot Q\ . \qquad (18)$$

There are two elements to an ash disposal system: the conveyor to move the ash and a pond in which to deposit it. The cost of an ash conveyor is proportional to the amount of ash to be moved and the length of the conveyor. The amount of ash to be moved by the conveyor is proportional to the gas flow rate. For flue gas flow rates less than 47.2 acms (100,000 acfm) a 23-cm (9-in) diameter pipe is sufficient and the cost of the conveyor is

$$CT_{con} = 632.5 + 216.5 \cdot L_c \qquad (19)$$

where L_c is the length of the conveyor. For larger gas flow rates, a 30-cm (12-in) pipe size is recommended. The cost of a 30-cm (12-in) diameter conveyor system is:

$$CT_{con} = 747.5 + 222.4 \cdot L_c \ . \qquad (20)$$

For the purposes of this study, a 305-m (1,000-ft) conveyor is assumed sufficient to transfer the fly ash from the baghouse hoppers to the ash pond.

It is assumed here that the fly ash collected in the baghouse has no intrinsic value and must be disposed of in an ash pond. The cost of the ash pond is dependent on its size, which is determined by the amount of ash collected. This cost is also dependent on the presence or absence of a flue gas desulfurization (FGD) unit in the pollution control system. If an FGD system is included, a larger pond will be required for ash disposal; however, because of a generous economy of scale, the unit cost will be lower. Only the portion of the ash pond needed for disposal of the baghouse fly ash is assigned to the control device for costing purposes. The amount of ash collected is the product of the amount of ash generated times the efficiency of the collector. The amount of fly ash generated in the boiler is calculated by

$$\text{ash generated} = \frac{\text{fraction fly ash} \times \text{boiler size}}{\text{coal heat value} \times \text{steam cycle efficiency}} \qquad (21)$$

where

fraction fly ash = fraction of ash in coal that leaves boiler in flue gas,

boiler size = net generating capacity

coal heat value = unit energy per unit mass

steam cycle efficiency = thermodynamic efficiency of energy conversion.

The amount of ash generated is calculated assuming 100 percent capacity; however, the pond size is calculated for the actual capacity:

$$\text{pond size} = 8.267 \cdot 10^{-2} \times \text{ash collected} \times \text{capacity factor} . \quad (22)$$

This equation yields pond size (acre-foot) assuming a pond life of 30 years. The constant 8.267×10^{-2} acre-ft/kg/h is derived from data reported by Ponder et al.[12] The cost of the pond is calculated from the equation

$$\text{actual pond cost} = 13{,}648 \times (\text{pond size})^{0.583} . \quad (23)$$

Equation 23 was derived from data in the report by Ponder et al.[12] and includes the cost of land, excavating, and diking. The constant 13,648 in the equation is the cost (in dollars) of a pond with 1 acre-ft of volume. Equation 23 does not include any charges for indirect costs or contingencies. These costs are included in the equation:

$$\text{total pond cost} = \text{actual pond cost} \times 1.395 \times 1.2 \quad (24)$$

where 1.395 is an indirect cost multiplier and the 1.2 is for a 20-percent contingency. The cost for the ash pond is primarily labor, thus the indirect multiplier in Equation 24 accounts for less overhead, freight, and insurance than it would in other subsystems.

4.3 ESFF HARDWARE

The cost of hardware required to equip a new conventional pulse-jet baghouse with ESFF or to retrofit an existing baghouse with ESFF is the same. A prototype baghouse was specified (see Figure 4-1) to determine these costs. For the sake of simplicity, it was assumed that the baghouse

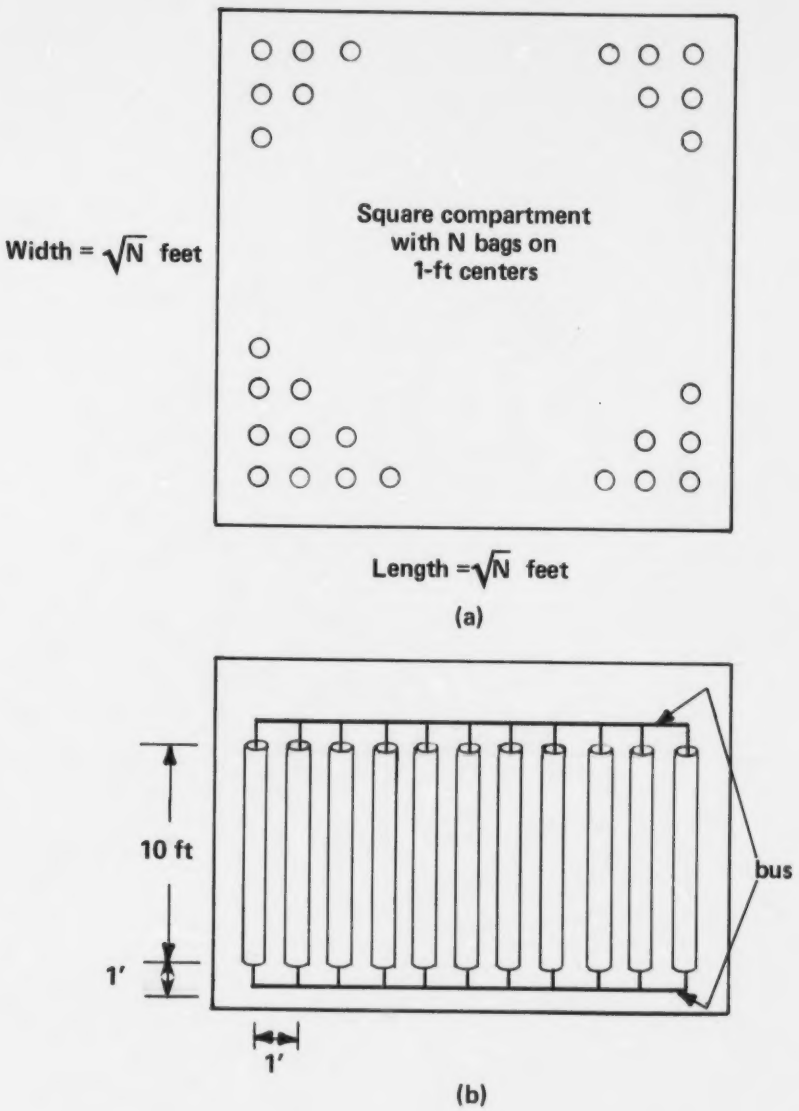
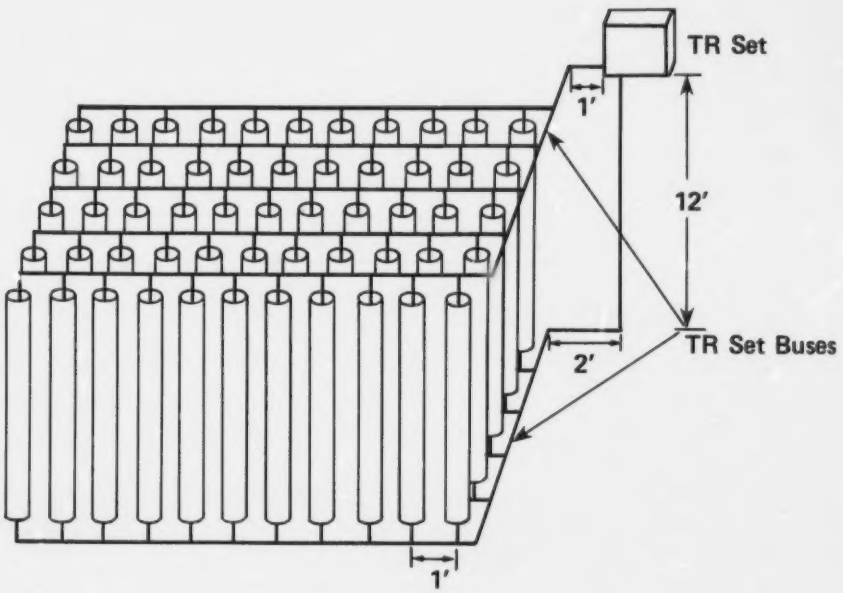


Figure 4-1. Assumed ESFF prototype.



(c)

Note: Each row of bags is connected to the TR set bus at the top and bottom.

Figure 4-1 (continued).

has only one large, square compartment. The bags in the prototype are placed on 0.3-m (1-ft) centers (i.e., 0.3 m apart.) Therefore, if there are N bags in the baghouse, the number of bags along any side of the compartment is $\sqrt{N}$. Since the bags are spaced 0.3 m (1 ft) apart, the length of the row of bags is $0.3 \cdot \sqrt{N}$ m (see Figure 4-1a).

The amount of wire needed to connect each of the bag cages to the transformer-rectifier set can be determined with the aid of Figure 4-1b. It has been assumed that the buses that carry the current for each row of bags are located 0.3 m above and below the row of bags. Thus, there must be 0.3 m of wire to connect each bag to the upper bus and 0.3 m of wire to connect each bag to the lower bus. The length of the bus is the same as the length of the row, or $\sqrt{N}$ m. Finally, each row of bag cages must be connected to the TR-set. This connection is illustrated in Figure 4-1c. The buses for each row of bags are connected to the TR-set buses by an 0.3 m length of wire at the end of the row. The TR-set buses extend the length of the baghouse so they are $0.3 \cdot \sqrt{N}$ m long. These TR-set buses are connected to the TR-set by the lengths of wire indicated in the figure. In summary, the amount of wire needed to connect a square baghouse with N bags to a power supply is:

Connect each bag to upper bus (N bags)	$0.3 \cdot N$	m
Connect each bag to lower bus (N bags)	$0.3 \cdot N$	m
Length of upper bus for each row, N rows	$0.3 \cdot N$	m
Length of lower bus for each row, N rows	$0.3 \cdot N$	m
Connect upper bus for each row to TR-set bus	$0.3 \cdot \sqrt{N}$	m
Connect lower bus for each row to TR-set bus	$0.3 \cdot \sqrt{N}$	m
Connect upper TR-set bus to TR-set	0.3	m
Connect lower TR-set bus to TR-set	4.2	m

Total wire required for baghouse $4.5 + 0.3\ (4N + 2\sqrt{N})$m

Other hardware required for ESFF installation includes connectors for coupling wires to buses (two per bag), clamps to hold the bus wires in place (two per bag), and ceramic plug connectors to make connections to bag cages. This hardware must be able to withstand the abrasive, high temperature, and occasionally acidic atmospheric within a baghouse. Likewise the wire used inside the baghouse must be able to withstand these conditions

with the added requirement that it be able to withstand the high voltages (0-5 kV) that are within the operating range of ESFF. For these reasons, 18-gauge, Teflon®-coated silver-plated copper wire rated to withstand 10 kV DC has been specified for the ESFF baghouse.

Operating experience has shown that a current density of 0.54 mA/m^2 of fabric area represents the upper limit of operation for ESFF. Currents higher than this can burn holes in the bag fabric. This current will be used when specifying the number of power supplies required for the baghouse. Because of the relatively low voltages required for ESFF as compared to an electrostatic precipitator, a power supply with dry insulation can be used. The TR set that is assumed for the prototype baghouse can supply a current of 1 amp at 10 kV with a primary voltage of 480 V.

Cost quotes have been obtained for all of these items and they are summarized in Table 4-4.

The cost of the ESFF hardware is the sum of the cost of the wire, the connector hardware, and the power supply:

$$C_{ESFF} = N \times \$6.20 + \$3.94 \times [4.5 + 0.3 \times (4N + 2\sqrt{N}) + \$1,835 \times \{7.85\ 10^{-4}\ N\} \quad (25)$$

The first term is the cost of the connector hardware, the second term is the cost of the wire, and the last term is the cost of the power supply based on a maximum current of 0.54 mA/m^2 and a bag area of 1.46 m^2 (6 in diameter, 10 ft length). The braces around the last term in the equation denote that an integer number of power supplies are required.

4.4 OPERATING AND MAINTENANCE COSTS

Operating costs include the cost of labor, materials, and energy to operate the baghouse. Some of these costs are fixed (i.e., determined by the size of the equipment) and some of the costs vary with the flow rate through the baghouse. As an example of a fixed charge, the cost of operating labor is calculated from the following formula:

$$\text{Cost of Op. Labor} = (8,760/8) \times (1.5+2.4 \times 10^{-4} \times A_n) \times 1.333 \times 1.8 \times olr \quad (26)$$

TABLE 4-4. ESFF HARDWARE COSTS

Ceramic plugs	2 per bag @ $2.00 ea =	$4.00 per bag
Bus connectors	2 per bag @ $1.00 ea =	$2.00 per bag
Wire clamps	2 per bag @ $0.10 ea =	$0.20 per bag
Total connector hardware		$6.20 per bag
Teflon® coated high voltage wire rated to 10 kV DC		$3.94/m
Transformer-rectifier set:		
1 amp, 10 kV, dry insulation, 480 V primary voltage, simple controls		$1,835 ea

where

A_n = net cloth area for flow in square meters, and

olr = operating labor rate ($/hr)

In this equation, the labor requirement is a minimum of 1.5 man-hours per shift with an additional man-hour per shift required for each 4,180 m^2 (45,000 ft^2) of cloth area in the baghouse. The first term in the equation is the number of shifts per year at 8,760 h/yr. The factor 1.333 includes a surcharge of 15 percent for supervision of operating labor at a labor rate 16 percent higher than the operator's rate (olr). The factor of 1.8 accounts for overhead.

Other fixed charges include the cost of maintenance labor and materials, bag replacement, and overhead. The cost of maintenance labor and materials is calculated as:

$$CT_{mlm} = (8{,}760/8) \cdot (1.5 + 2.4 \cdot 10^{-7} \cdot A_n) \cdot 0.5 \cdot 2.0 \cdot 1.8 \cdot mlr \quad (27)$$

where the first two terms are the same as in the operating labor equation. The 0.5 is used to indicate that the requirement of maintenance labor is one-half that of operating labor. It is assumed that maintenance material and labor costs will be equivalent, so the term 2.0 is used to account for maintenance materials. The multiplier of 1.8 accounts for overhead and the term mlr stands for maintenance labor rate which will generally be higher than the operating labor rate.

Bag replacement cost is another item that varies with size of the baghouse. This cost can be calculated from the equation

$$CT_{rep} = (1+OHF) \cdot CT_{fab}/\text{bag life} \cdot \begin{cases} 4.49 \cdot A_n^{0.835}, & A_n < 5{,}110\ m^2 \\ 1.75 \cdot A_n^{0.946}, & 5{,}110 < A_n < 16{,}722\ m^2 \\ 1.04 \cdot A_n, & An > 16{,}722\ m^2 \end{cases} \quad (28)$$

where

CT_{rep} = the cost of replacing the bags and cages

CT_{fab} = the unit cost of the fabric

OHF = a multiplier that accounts for overhead costs.

Implicit in this equation is the assumption that the replacement cost is spread evenly over the life of the bags. If this assumption is not valid (i.e., all bags are replaced in a single year), there will be a small error in the measure of merit calculated below.

The cost of compressed air for the cleaning pulse of the pulse-jet baghouse is also assumed to be independent of flow through the baghouse. This annual cost is calculated as

$$CT_{pulse} = 66.74 \cdot CT_{kWh} \cdot \begin{cases} 4.49 \cdot A_n^{0.835}, & A_n < 5{,}110 \text{ m}^2 \\ 1.75 \cdot A_n^{0.946}, & 5{,}110 < A_n < 16{,}722 \text{ m}^2 \\ 1.04 \cdot A_n, & A_n > 16{,}722 \text{ m}^2 \end{cases} \quad (29)$$

based on 25 ft^3/min of air for each 1,000 ft^2 of fabric, where CT_{kWh} is the cost of electricity per kilowatt hour.

The only other annual costs that are independent of flow rate through the baghouse are the administration, taxes, and insurance costs. These costs are assumed to be constant percentages of the turnkey cost of the baghouse.

The only variable baghouse costs are associated with electricity for fans and ash removal equipment. The annual cost of electricity for a fan operating 8,760 h/yr at a motor efficiency of 90 percent and a fan efficiency of 60 percent is

$$CT_{fms} = 8{,}760 \cdot 0.182 \cdot Q \cdot \Delta P_{ave} \cdot CT_{kWh} \quad (30)$$

where

Q = the flow rate in acms

ΔP_{ave} = the average pressure drop across the baghouse in cm H_2O.

This cost can be modified further by the plant capacity factor. That is, if a plant is only operating at 70 percent of capacity, the cost of electri-

city for the fan will be 70 percent of the value calculated above. Similarly, the cost of electricity for conveying fly ash is

$$CT_{ash} = 3.48 \cdot 10^5 \cdot Q \cdot C_{in} \qquad (31)$$

where

C_{in} = the concentration of fly ash at the inlet of the baghouse in kg/m^3.

The electricity requirement for the ESFF cages is the product of the applied field, the current, and the number of hours the unit is in operation. Specifically,

$$\text{ESFF power} = \text{Applied field} \cdot \text{electrode spacing} \cdot \text{bag area} \cdot \frac{\text{current density}}{0.6} \cdot 8{,}760 \qquad (32)$$

The constant 0.6 is the assumed efficiency of a.c. to d.c. conversion. The current density used in this equation is the average operating current density. Experience[1] has shown that an operating current density of 0.27 mA/m^2 is sufficient for ESFF.

The total annual operating and maintenance cost is the sum of the operating labor; maintenance labor and material; bag replacement labor and material; and electricity cost for the compressed air source, ID fan, ash pumps, and ESFF hardware.

4.5 ANNUAL CAPITAL COST

When the Navy purchases equipment, it does not have to consider the cost of financing that purchase, but for those who wish to use this model for predicting the costs to public utilities or industrial organizations, the financing cost must be included. The capital recovery factor is used to determine the annual payment of principal and interest. This payment is calculated according to the formula:

$$A = P \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (33)$$

where

A = annual payment,
P = capital cost,
i = annual interest rate, and
N = life of the equipment.

The total annual cost can then be calculated as the annual payment for capital equipment plus the annual operating and maintenance costs.

4.6 EXAMPLE CALCULATIONS

As an example of the application of the capital and O&M cost equations, consider the following comparison between a conventional pulse-jet baghouse and an ESFF pulse-jet baghouse. Both baghouses are designed to produce an average pressure drop of 10 cm H_2O; but the conventional baghouse is designed with an air-to-cloth ratio of 0.02 $(m^3/s)/m^2$ whereas the ESFF baghouse can operate at 0.03 $(m^3/s)/m^2$. Other pertinent parameters are listed in Table 4-5.

The capital and O&M costs will be computed along with the Net Present Value and the Equivalent Uniform Annual Cost.

For the ESFF baghouse, the cost of the equipment can be determined from Equations 14 through 25 based on a net cloth area of

$$A_n = \frac{200\ m^3/s}{0.03\ (m^3/s)/m^2} = 6{,}667\ m^2$$

and the number of bags in the ESFF baghouse is

$$N = 6{,}667\ m^2/1.46\ m^2/bag = 4{,}566\ bags\ .$$

$$CT_b = 5{,}370 + 81.8 \times 6{,}667 = \$\ 550{,}731$$

$$CT_{ESFF} = 6.2 \times 4{,}566 + 3.94 \times (4.5 + 0.3\ (4 \times 4{,}566 + 2\sqrt{4{,}566})) + 1{,}835\ \{7.85 \times 10^{-4} \times 4{,}566\} = 57{,}415$$

$$CT_{ins} = 4{,}910 + 25.8 \times 6{,}667 = 176{,}919$$

$$CT_{duct} = 15.2\ (-5.77 + 177 \times 1.128 \times 0.2562(200)^{\frac{1}{2}}) = 10{,}908$$

TABLE 4-5. DESIGN AND OPERATING PARAMETERS FOR THE EXAMPLE CALCULATIONS

Flowrate	200 m^3/s
Inlet dust concentration	7 g/m^3
Operating labor rate	$10.00/hr
Maintenance labor rate	$12.00/hr
Material overhead fraction	10%
Cost of fabric	$4.65/$m^2$
Bag life	4 years
Unit cost of electricity	$0.06/kWh
Average pressure drop	10.0 cm H_2O
Applied field strength	3.0 kV/cm
Equipment life	15 years
Effective annual discount rate	12.0%

CT_{damp} = 1,100 + 64.8 × 200 = $ 14,060

CT_{fms} = 2,600 + 528.5 × 200 = 108,300

CT_{con} = 747.5 + 222.4 × 305 = 68,580

Pond size = 8.267×10^{-2} acre-ft/kg/hr × 7×10^{-3} kg/m³ × 200 m³/s × 3,600 s/hr

= 416.6 acre-ft

Pond cost = 13,648 $(416.6)^{0.583}$ = 459,621

Total $1,446,534

The purchased equipment cost can be calculated using the factors listed in Table 4-1.

Purchased Equipment Costs		
Baghouse		$ 550,731
ESFF hardware		57,415
Auxiliary equipment		838,388
Instruments and controls	0.10 × 1,446,534 =	144,653
Taxes	0.03 × 1,446,534 =	43,396
Freight	0.05 × 1,446,534 =	72,327
Purchased equipment cost		$1,706,910

The installation costs and indirect costs are also calculated using the factors in Table 4-1 and based on purchased equipment cost.

Installation Costs		
Foundations and supports	0.04 × 1,706,910 =	$ 68,276
Erection and handling	0.50 × 1,706,910 =	853,455
Electrical	0.08 × 1,706,910 =	136,553
Piping	0.01 × 1,706,910 =	17,069
Insulation	0.07 × 1,706,910 =	119,484
Painting	0.02 × 1,706,910 =	34,138
Site preparation	0.01 × 1,706,910 =	17,069
Facilities and buildings	0.02 × 1,706,910 =	34,138
Total		$1,280,182

Indirect Costs		
Engineering and supervision	0.10 × 1,706,910 =	$ 170,691
Construction and field expenses	0.20 × 1,706,910 =	341,382
Construction fee	0.10 × 1,706,910 =	170,691
Startup	0.01 × 1,706,910 =	17,069
Performance test	0.01 × 1,706,910 =	17,069
Contingencies	0.03 × 1,706,910 =	51,207
Total		$ 768,109

Capital cost = $1,706,910 + $1,280,182 + $768,110 = $3,755,202

Thus the capital cost is $3.76 million.

In the calculation that led to the value of $3.76 million, it was assumed that the process in question is well established. This assumption is inappropriate for ESFF at this time. According to Table 4-2 the engineering and supervision cost and the allowance for contingencies should be increased when the process is not well established. The engineering cost should be tripled and the contingency allowance should be increased by a factor between 3 and 5. The cost of the baghouse would thus be:

Purchased equipment cost		$1,706,910
Installation cost		$1,280,182
Indirect Costs		
Engineering and supervision	3 × 0.10 × 1,706,910 =	$ 512,073
Construction and field expenses	0.20 × 1,706,910 =	341,382
Construction fee	0.10 × 1,706,910 =	170,691
Startup	0.01 × 1,706,910 =	17,069
Performance test	0.01 × 1,706,910 =	17,069
Contingencies	5 × 0.03 × 1,706,910 =	256,036
Total		$1,314,320

Capital cost = $1,706,910 + $1,280,182 + $1,314,321 = $4,301,413

This is the capital cost of the ESFF baghouse with the cost of inexperience and uncertainty taken into account.

The cost of the conventional pulse-jet baghouse can be estimated based on a net cloth area of:

$$A_n = \frac{200\ m^3/s}{0.02\ (m^3/s)/m^2} = 10,000\ m^2$$

and the number of bags is

$$N = 10,000\ m^2/1.46\ m^2/bag = 6,850\ bags.$$

The capital cost of the conventional baghouse can be calculated as above, excluding the ESFF hardware costs and the "uncertainty" costs. The resulting capital cost is $4.74 million. This cost is higher than the cost of the ESFF pulse-jet baghouse because it is 50 percent larger.

The annual operating and maintenance cost for the ESFF baghouse can be calculated with equations 26 through 32.

$CT_{op\ labor} = (8{,}760/8) \times (1.5 + 2.4 \times 10^{-4} \times 6{,}667) \times 1.333 \times 1.8 \times 10.0 = \$81{,}468$

$CT_{min} = (8{,}760/8) \times (1.5 + 2.4 \times 10^{-4} \times 6{,}667) \times 1.8 \times 12.0 = \$73{,}321$

$CT_{rep} = (1 + 0.1) \times (4.65/4) \times 1.75\ (6{,}667)^{0.946} = \$9{,}274$

$CT_{pulse} = 66.74 \times 0.06 \times 1.75\ (6{,}667)^{0.946} = \$29{,}041$

$CT_{fms} = 8{,}760 \times 0.182 \times 200 \times 10 \times 0.06 = \$191{,}318$

$CT_{ash} = 3.48 \times 10^{5} \times 200 \times 7 \times 10^{-3} = \$487{,}200$

$ESFF_{power} = 3.0 \times 2 \times 6{,}667\ (0.27/0.6) \times 8{,}760 \times 0.06/1{,}000 = \$9{,}461$

Total Direct Operating Costs 881,083

Indirect Operating Costs

Overhead = 0.8 × (81,468 + 73,321)	=$123,831
Property tax (no property tax on Government property)	0
Insurance = 0.01 × (4.3 × 10^6)	= 43,000
Administration = 0.02 × (4.3 × 10^6)	= 86,000
Capital recovery cost (no capital recovery costs for Government purchases)	0
Total indirect operating costs	=$252,831

Total annual operating costs = 881,083 + 252,831 = $1,133,914

The high cost of ash disposal in the above calculations is due to the high inlet dust loading.

A similar analysis for a conventional pulse-jet baghouse, excluding ESFF power costs, yields a Direct Operating Cost of $929,448 and an Indirect Cost of $297,988. The Total Annual Operating Cost is thus $1.23 million. The operating costs for the conventional baghouse are higher than the costs for the ESFF baghouse because the operating labor costs and maintenance labor and material costs are assumed proportional to the size of the baghouse. Thus, the size difference greatly outweighs the magnitude of the ESFF power, so the ESFF operating costs are actually less than the conventional operating costs.

Now that the capital and operating costs have been estimated, the Net Present Value can be calculated.

NPV = capital cost + annual O&M cost × cumulative uniform series factor ESFF baghouse:

$$NPV = \$4.3 \times 10^6 + \$1.13 \times 10^6 \cdot \frac{\exp(15 \cdot \ln(1 + 0.12)) - 1)}{\ln(1 + 0.12) \cdot \exp(15 \cdot \ln(1 + 0.12)}$$

$$= \$4.3 \times 10^6 + \$1.13 \times 10^6 \cdot 7.2118$$

$$= \$12.45 \times 10^6.$$

$$\text{Equivalent Uniform Annual Cost (EUAC)} = \frac{\text{Net Present Value (NPV)}}{\text{Cumulative Uniform Series Factor}}$$

$$= \frac{\$12.45 \times 10^6}{7.2118} = \$1.73 \times 10^6 \quad .$$

Conventional Baghouse

$$NPV = \$4.74 \times 10^6 + \$1.23 \times 10^6 \cdot 7.2118$$

$$= \$13.61 \times 10^6$$

$$EUAC = \frac{\$13.61 \times 10^6}{7.2118} = \$1.89 \times 10^6 \quad .$$

Thus, in terms of the equivalent uniform annual cost, the conventional baghouse costs $160,000/yr more than the ESFF baghouse. Based on the design parameters listed in Table 4-5, the preceding analysis indicates that an ESFF baghouse would be the best choice.

4.7 ACCURACY OF CAPITAL COST PREDICTIONS

All of the equations presented in Section 4.2 for predicting the cost of equipment were developed from vendor quotes. One of the subtasks of this contract was to develop an independent check of the accuracy of those equations. Unfortunately, there is very little data published in the literature on the cost of pulse-jet baghouses. As a result, ETS, Inc., of Roanoke, Virginia, was hired as a consultant with the task of obtaining new

vendor quotes for pulse-jet baghouses. The report from ETS is included in Appendix C of this report.

Three different sizes of baghouses were priced: 26 acms, 85 acms, and 165 acms (55, 180, and 350 k acfm). The equipment includes the baghouse, insulation for the baghouse, woven glass bags and cages, inlet and outlet manifolds and dampers, hopper heaters, controls, and structural supports. The baghouses were specified with air-to-cloth ratios of 0.02 m/s (4 ft/min). With this information, equations 15, 16, 18, and 29 were used to develop the costs in Table 4-6. The quotes obtained by ETS include the cost of controls and structural supports for the baghouse. To account for these costs, the factor in Table 4-1 for instrumentation and controls (10%) was applied to the sum of the capital costs to get an estimate of the purchased equipment cost. The cost of structural support was estimated with the factor from Table 4-1 based on the purchased equipment cost. The calculated cost is in terms of December 1977 dollars so the calculated costs are multiplied by the ratio of the Chemical Engineering plant cost indexes for 1977 and 1983 (310/204).

The agreement between the predicted values and the reported values is surprising in view of the fact that they are both based on vendor quotes. Typically such price quotes can vary by a factor of 2 between different vendors. It should be noted that the cost modeling equations are based on design standards that are at least 7 years old, so that changes since then are not included in the costs reported in the table. It should also be noted that this comparison does not include the price of ducting, ash conveying systems, ash ponds, or installation. Also, at the time of this writing there are no data available to validate the ESFF costs.

In summary, the equations for predicting the cost of the baghouse, insulation, dampers, and fabric seem to be in good agreement with expected values. The cost predictions of ESFF hardware, other auxiliary equipment, and operating and maintenance costs have not been validated. Neveril reports that the capital and operating and maintenance cost equations (except the ESFF hardware) should be accurate to ±20 percent and this is consistent with the results presented here. The reliability of the cost equation for ESFF hardware is unknown. The prototype system specified in

TABLE 4-6. COMPARISON BETWEEN PREDICTED VALUES AND VENDOR QUOTES

Item	Equation No.	Cost ($) Q = 26 m^3/s A = 1,275 m^2	Q = 85 m^3/s A = 4,274 m^2	Q = 165 m^3/s A = 8,194 m^3
Baghouse	14	109,870	354,970	675,690
Insulation	15	37,910	115,310	216,590
Bags	28 (OHF = 0.1, C_F = 0.6)	11,380	31,192	57,034
Dampers	17	2,783	6,608	11,810
Total		161,943	508,080	961,124
Instruments and controls (Table 4-1: 10%)		16,194	50,808	96,112
Purchased equipment cost		178,137	558,888	1,057,236
Foundation and supports (Table 4-1: 4%)		7,125	22,356	42,289
Capital cost (December 1977)		185,262	581,244	1,099,525
Purchased equipment cost (CE plant cost index) (mid-1983)		281,526	883,263	1,670,847
Unit cost ($/$m^2$ fabric)		221	207	204
Vendor quote ($/$m^2$ fabric)		258	215	183
Ratio: Predicted cost/ vendor quote		0.856	0.963	1.115

Section 4.2 is quite simple and it is likely that some necessary items have been overlooked. On the other hand, the cost of the connector hardware seems high. In situations like this, where the technology is new and has never been implemented on a full scale, it is common to specify the accuracy as ±30%.

CHAPTER 5

COMPUTER PROGRAM

A computer program has been written that incorporates the performance and cost models described earlier. The program allows the user to predict pulse-jet baghouse performance, and then use the air-to-cloth ratio, air flow rate, and the predicted pressure drop to predict the capital cost and annual operating costs. The appropriate measure of merit (NPV for new baghouses and SIR and payback period for baghouses retrofit with ESFF hardware) is calculated from the predicted values.

In the following sections instructions are given for program operation. A thorough breakdown of the program structure and a list of program variables are also given as an aid to future modifications.

5.1 SYSTEM REQUIREMENTS

The computer program (called PULSEJET) was developed for two different types of microcomputers: the Tektronix series 4050 computers and the TRS80 Models I and III. For the PULSEJET program to run successfully on a Tektronix 4051, 4052, or 4054, the computer must have a minimum of 32 kilobytes of available memory (RAM). Floppy disk drives are not required for program operation. The program will provide hard copies of the program input and output on a Tektronix Hard Copy Unit if it is available.

The minimum system required to run the TRS80 version of the program includes a TRS-80 Model I or III microcomputer with 32 kilobytes of available memory and one 5-1/4-in floppy disk drive. The program requires either the TRSDOS® or NEWDOS® Disk Operating System (DOS) or any other DOS that is capable of running Microsoft Disk Basic and is file-compatible with TRSDOS. The pulse-jet program is also designed to provide a listing of results on a line printer (e.g., Radio Shack Line Printers VII or VIII). It is desirable to have all of the computer equipment plugged into a single, switched outlet strip so that everything can be turned on at once. If the

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computer has two or more disk drives, it is recommended that the PULSEJET program be placed on a write-protected disk along with a DOS.

5.2 BACKGROUND INFORMATION

This chapter is not intended to introduce the reader to computers. It is assumed that the reader knows how to operate the computer and to handle tape cartridges properly (for Tektronix computers) and/or floppy diskettes (for TRS-80 computers). Those not familiar with the proper methods for computer operation should refer to the appropriate reference manual--either the Graphics System Reference Manual for the Tektronix or the TRSDOS & DISK BASIC Reference Manual for the TRS-80 computer.

There is very little system-specific information necessary to execute PULSEJET on the Tektronix computers; however, the user should be familiar with the keyboard and the AUTO LOAD button. The TRS-80 user should be familiar with the BASIC, LOAD, and RUN commands.

Regardless of which computer is used, it is strongly recommended that the reader make a spare copy of the PULSEJET program and store it in a safe place. This is protection in the event that the original copy of the program is lost or destroyed.

The PULSEJET program is just a tool, and, as with any tool, the best way to become familiar with it is to use it; but a brief look at the program structure is first in order. Figure 5-1 is a simplified flow chart of the PULSEJET program. The program begins by assigning default values to program variables and setting up character strings. The first input item called for by the program is the date. This will be used to help document the results. Next the user is given the opportunity to select English or metric units for the program parameters. Of course the results are unaffected by this choice; it is simply an option to allow the program operator a choice of units for entering program parameters. It should be noted that once a set of units has been chosen, all affected parameters will be in those units and the only way to switch to the other set of units is by restarting the program.

After the system of units has been specified, the program prints the Main Menu. This menu is the heart of the program as well as its key to flexibility and ease of use. The Main Menu presents eight options that

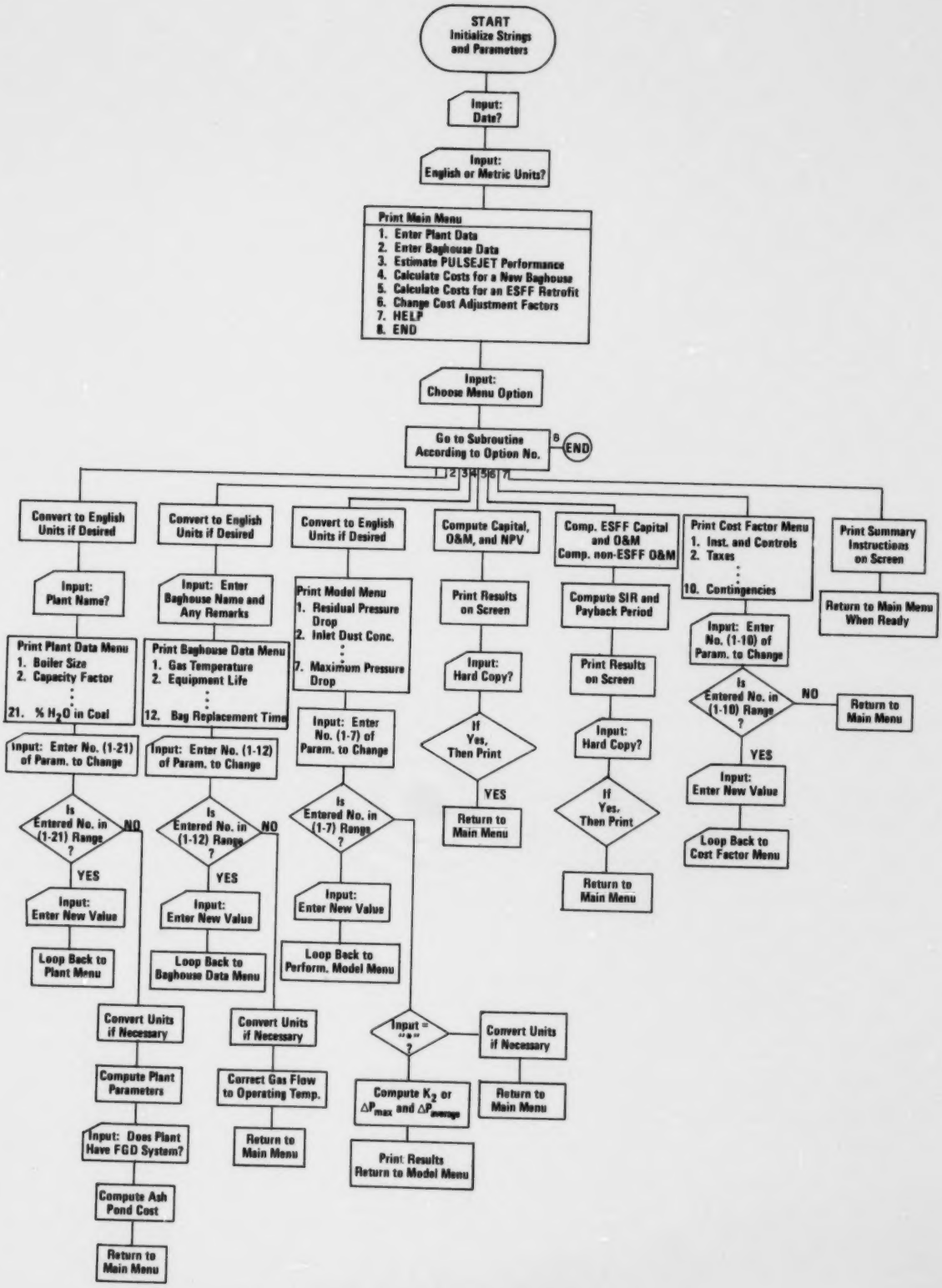
START
Initialize Strings and Parameters
Input: Data?
Input: English or Metric Units?
Print Main Menu
1. Enter Plant Data
2. Enter Baghouse Data
3. Estimate PULSEJET Performance
4. Calculate Costs for a New Baghouse
5. Calculate Costs for an ESFF Retrofit
6. Change Cost Adjustment Factors
7. HELP
8. END
Input: Choose Menu Option
Go to Subroutine According to Option No.
8
END
1 2 3 4 5 6 7
Convert to English Units if Desired
Input: Plant Name?
Print Plant Data Menu
1. Boiler Size
2. Capacity Factor
21. % H_2O in Coal
Input: Enter No. (1-21) of Param. to Change
Is Entered No. in (1-21) Range ?
NO
YES
Input: Enter New Value
Loop Back to Plant Menu
Convert to English Units if Desired
Input: Enter Baghouse Name and Any Remarks
Print Baghouse Data Menu
1. Gas Temperature
2. Equipment Life
12. Bag Replacement Time
Input: Enter No. (1-12) of Param. to Change
Is Entered No. in (1-12) Range ?
NO
YES
Input: Enter New Value
Loop Back to Baghouse Data Menu
Convert to English Units if Desired
Print Model Menu
1. Residual Pressure Drop
2. Inlet Dust Conc.
7. Maximum Pressure Drop
Input: Enter No. (1-7) of Param. to Change
Is Entered No. in (1-7) Range ?
Input: Enter New Value
Loop Back to Perform. Model Menu
Compute Capital, O&M, and NPV
Print Results on Screen
Input: Hard Copy?
If Yes, Then Print
YES
Return to Main Menu
Comp. ESFF Capital and O&M
Comp. non-ESFF O&M
Compute SIR and Payback Period
Print Results on Screen
Input: Hard Copy?
If Yes, Then Print
Return to Main Menu
Print Cost Factor Menu
1. Inst. and Controls
2. Taxes
10. Contingencies
Input: Enter No. (1-10) of Param. to Change
Is Entered No. in (1-10) Range ?
NO
Return to Main Menu
YES
Input: Enter New Value
Loop Back to Cost Factor Menu
Print Summary Instructions on Screen
Return to Main Menu When Ready
Convert Units if Necessary
Compute Plant Parameters
Input: Does Plant Have FGD System?
Compute Ash Pond Cost
Return to Main Menu
Convert Units if Necessary
Correct Gas Flow to Operating Temp.
Return to Main Menu
Input = "a" ?
Convert Units if Necessary
Compute K_2 or ΔP_{max} and $\Delta P_{average}$
Return to Main Menu
Print Results Return to Model Menu

Figure 5-1. Program flow chart.

can be exercised by the user. When an option is chosen, the program executes one or more subroutines that may also contain menues and returns to the Main Menu when that option has been completed. For example, option number seven is the HELP routine. When the operator chooses this option, the program will print a summary of instructions on how to use the program. When the instructions have been read, the program will return to the Main Menu. There is no limit on the number of times an option can be called. Similarly, there are no restrictions on the order in which options can be called.

The menu format of the PULSEJET program makes it very easy to use. The program can be mastered by anyone, regardless of prior experience with computers. In the next section, step-by-step instructions on how to operate the program to evaluate a proposed ESFF baghouse will be given.

5.3 SAMPLE SESSION OF PULSEJET EXECUTION

The instructions that follow applies to both the Tektronix and the TRS-80 computers. Program execution is virtually identical for each machine; however, the differences will be explained fully.

On the Tektronix computer, turn on the power, insert the tape cartridge, and press the AUTO LOAD button on the keyboard. The PULSEJET program will be loaded from the tape and execution will begin. (It has been assumed here that PULSEJET is the first file on the tape.) From DISK BASIC on the TRS-80 type RUN"PULSEJET/BAS." The program will be loaded from the floppy disk and execution will begin. The first thing the program does is print a heading on the screen as shown in Figure 5-2. There may be a slight pause while the program initializes variables and strings, but soon the program will ask for the date. The program is expecting a character string, so any format can be used (e.g., 10/31/82 or Oct. 31, '82, etc.). Immediately after the date has been entered, the program will give the user the opportunity to specify English or metric units. For this example, press either E or e and RETURN.

Immediately after the system of units has been chosen, the screen will clear and the Main Menu will be written as shown in Figure 5-3. As a simple demonstration of the menu approach to program execution, choose the

```
**********************************************************************
          Pulse Jet Cost and Performance Models
**********************************************************************
     DATE : 1/11/83

DO YOU WANT ENGLISH OR METRIC UNITS (E OR M) e
```

Figure 5-2. At the beginning of the PULSEJET program, a heading is printed and then there is a pause while some variables are initialized. The date is the first item requested. It can be entered in any format.

```
**********************************************************************
Pulse Jet Cost and Performance Models - Main Menu
**********************************************************************

                    1. Enter Plant Data

                    2. Enter Baghouse Data

                    3. Estimate Pulse Jet Performance

                    4. Calculate Costs for a New Baghouse

                    5. Calculate Costs for ESFF retrofit

                    6. Change Cost Adjustment Factors

                    7. HELP

                    8. END

              Which option would you like to run (1-8)
```

Figure 5-3. The main menu of the PULSEJET program presents the user with 8 options.

HELP option by typing the number 7, followed by RETURN. The screen will clear and the message shown in Figure 5-4 will be printed on the screen. Press any key, except SHIFT, followed by RETURN to return to the Main Menu. The program returns to the Main Menu and waits for selection of another option.

Now consider the following scenario: A new boiler with attendant pollution controls is to be installed in a plant. There is already one boiler operating at this plant and a pulse-jet baghouse is used for particulate control. The new boiler is identical to the existing one so it can be assumed that the gas flow rate and emissions from the boiler will also be the same. The PULSEJET program can help determine whether or not an ESFF baghouse offers any advantages over a conventional pulse-jet baghouse for the new boiler.

One of the required steps for estimating the cost is to specify the plant parameters. From the Main Menu choose option number 1 by pressing the number 1 followed by the RETURN key. The program will clear the screen and ask for the Plant Name. Enter any name that will identify this plant and press RETURN. The Plant Data Menu will then appear on the screen as shown in Figure 5-5a for the Tektronix computers. Figure 5-5b shows the equivalent screen display for the TRS-80. This menu contains parameters that determine the size of the boiler, the amount of emissions from the boiler, current cost escalation factors, and the current discount rate. The numbers listed in the far left column on the display are for identification of the parameter described in that row. The numbers in the far right column are the values currently assigned to the parameter. When this menu is displayed for the first time, the default values for those parameters are shown. The default values are there simply for convenience. If the default value is adequate, there is no need to change it. They also serve to fill in the gaps where values are unknown. Thus, the default value of item number 1 (Boiler Size) is 3.4 MBtu/h. For this case study, assume that the boiler size will be 5.0 MBtu/h. Therefore, the value listed on the screen must be changed. To do this, press 1 to identify item number 1 and RETURN. The current value of Boiler Size will be printed along with the question "New value?" (see Figure 5-6). Enter 5.0 and press RETURN.

```
********** HELP **********

     The screen which you just saw listed eight options
which are available to you.  To execute any one of these
options press a number between 1 and 8 followed by the
RETURN key.  The program will execute the subroutine(s)
which corresponds to that option number.  When that routine
has been completed the program will return to the Main
Menu.  The order in which the options are selected does not
matter.  You can execute any of the subroutines any number
of times.

     The data input options (1 and 2) and the Performance
Modeling option also present you with menus.  In these menus
you are presented with a list of parameters and their
values.  To change one of the values, enter its ID number
(the number in the left-hand column) followed by RETURN.
Enter the new value for that parameter followed by RETURN.
The screen will be rewritten with the new value.

     For complete instructions consult the PULSEJET users
documentation.

Press RETURN to continue
```

Figure 5-4. A brief description of how to run the program is printed on the screen when the operator chooses the HELP option.

```
**********************************************************************
Data for Plant demo1
**********************************************************************
 1 Boiler Size                                        3.41  MBtu/hr
 2 Capacity Factor                                    70.0
 3 Chem. Eng. Plant Cost Index                       270.0
 4 Emission Limit                                      0.1  lb/MBtu
 5 Plant Altitude                                        0  ft
 6 Effective Annual Discount Rate                    10.00  /yr
 7 Cost of Electricity                               30.00  mil/kwh
 8 Contingency as Percent of Field Cost              20.0   %
 9 Engineering as Percent of Field Cost              20.0   %
10 Steam Cycle Efficiency                            85.0   %
11 Gas Flow Rate                                        0   Kacfm
12 Boiler Emissions                                   0.0   lb/MBtu
13 Coal Heating Value                                9993   Btu/lb
14 Fraction Excess Air                                0.25
15 Percent Carbon in Coal                            60.00  %
16 Percent Hydrogen in Coal                           5.40  %
17 Percent Oxygen in Coal                            11.20  %
18 Percent Sulfur in Coal                             0.60  %
19 Percent Nitrogen in Coal                           1.60  %
20 Percent Ash in Coal                                7.60  %
21 Percent Water in Coal                             13.60  %

Enter the number of the item you want to change or enter
* to exit from this routine
```

Figure 5-5a. Plant data menu showing default values for each parameter (Tektronix version).

```
**********************************************************************
Data for Plant demo1                          Page 1 of 2
**********************************************************************
 1 Boiler Size                                    3.41 MBtu/hr
 2 Capacity Factor                               70.0
 3 Chem. Eng. Plant Cost Index                  310.0
 4 Emission Limit                                0.1  lb/Mbtu
 5 Plant Altitude                                0    ft
 6 Effective Annual Discount Rate               10.00 %/yr
 7 Cost of Electricity                          30.00 mil/kwh
 8 Contingency as Percent of Field Cost         20.0  %
 9 Engineering as Percent of Field Cost         20.0  %
10 Steam Cycle Efficiency                       85.0  %
Enter the number of the item you want to change; > to go
to the next page; or * to exit from this routine
```

Figure 5-5b. In the TRS-80 version of the program the plant data menu is divided into two "pages".

```
**********************************************************************
Data for Plant demo1
**********************************************************************
 1 Boiler Size                                      3.41 MBtu/hr
 2 Capacity Factor                                 70.0
 3 Chem. Eng. Plant Cost Index                    270.0
 4 Emission Limit                                   0.1  lb/MBtu
 5 Plant Altitude                                   0    ft
 6 Effective Annual Discount Rate                  10.00 /yr
 7 Cost of Electricity                             30.00 mil/kwh
 8 Contingency as Percent of Field Cost            20.0  %
 9 Engineering as Percent of Field Cost            20.0  %
10 Steam Cycle Efficiency                          85.0  %
11 Gas Flow Rate                                    0    Kacfm
12 Boiler Emissions                                 0.0  lb/MBtu
13 Coal Heating Value                            9993    Btu/lb
14 Fraction Excess Air                              0.25
15 Percent Carbon in Coal                          60.00 %
16 Percent Hydrogen in Coal                         5.40 %
17 Percent Oxygen in Coal                          11.20 %
18 Percent Sulfur in Coal                           0.60 %
19 Percent Nitrogen in Coal                         1.60 %
20 Percent Ash in Coal                              7.60 %
21 Percent Water in Coal                           13.60 %

Enter the number of the item you want to change or enter
* to exit from this routine 1

Boiler Size                                    3.41  New value =
```

Figure 5-6. A value is changed by specifying the corresponding item number (1-21). The program prints the current value and asks the user for the new value.

The screen will clear and the Plant Data Menu will be rewritten with the new value for Boiler Size while the other values remain unchanged. Thus, to change any value, specify the parameter to be changed by its identification number (1-21) and then enter the new value.

For the TRS-80 version of PULSEJET there are more plant parameters than can fit on the screen at one time. For this reason, the Plant Data Menu is split into two "pages". A page is simply a screen full of information. When the Plant Data Menu is called, only the first 10 items of the menu are displayed. To see the remaining 11 items, press the greater-than symbol (>) and RETURN. To return to the first page of the menu, press the less-than symbol (<) and RETURN. This is the only difference between the two versions of the program in this option. The parameter values are changed in the same manner as described above.

One other point about the Plant Data Menu concerns the gas flow rate and boiler emissions option. These are listed as items number 11 and 12 in the Plant Data Menu. The default values for these parameters are both zero, since it is assumed that they are to be calculated from the coal analysis (items 13-21). For this case study, since the new boiler is identical to the existing boiler whose gas flow rate is known, the gas flow rate can be entered; likewise for the boiler emissions. Enter a value of 10 k acfm (i.e., 10,000 acfm) for item 11 and 100 lb/MBtu for the boiler emissions (item 12).

When all of the proper values have been entered into the Plant Data Menu, press the asterisk key (*) followed by RETURN. The program will do some calculations and then ask if an FGD system is included with the plant. For this example, answer N and press RETURN. This completes the Plant Data Input option. The Main Menu will be redisplayed on the screen.

The next step in estimating the cost of an ESFF baghouse is to predict its performance. This can be done with the aid of option number 3 of the PULSEJET program. Select option 3 from the Main Menu. The display should appear as in Figure 5-7. Each of the first four values listed must be specified. That is, the user must enter a nonzero value or leave the default value unchanged. Of the last three values, at least one must be entered. Note that the maximum pressure drop in the filtering/cleaning

```
**********************************************************************
Pulse Jet Performance Model
**********************************************************************
 1 Residual Pressure Drop                          1.97   in H2O
 2 Inlet Dust Concentration                        0.31   lb/ft3
 3 Time between Cleaning Cycles                    1.000  min
 4 Air to Cloth Ratio                              2.07   ft/min
 5 Applied Field                                   0.00   KV
 6 Specific Resistance Coefficient (K2)           17.96   dP/VW
 7 Maximum Pressure Drop                           0.0    in H2O

Enter the number of the item you want to change or enter
 * to perform calculations or enter ** to exit from this
subroutine.
```

Figure 5-7. Input menu for the PULSEJET performance model.

cycle (item number 7) is required only when K_2' is unknown, in which case K_2' is calculated as shown in Table 2-1. The user can specify an ESFF baghouse by entering a positive value for the Applied Field, or specify a conventional baghouse by leaving this value at zero.

For this case study, assume that items 1, 2, 3, 4, and 7 are known for the conventional baghouse. Assume that the default values for items 1 through 4 as shown in Figure 5-7 are the correct values for this plant, but that the K_2' is unknown. Enter a value of 10.0 in. H_2O for the maximum pressure drop. Notice that when a value is entered for item 7, the value of K_2' is automatically set to zero by the program. Now begin the computation by pressing * and RETURN. The program will compute K_2' and display the result as shown in Figure 5-8. At this time the user has the option of printing the results or continuing computation. In either case the program redisplays the menu with the computed value of K_2' inserted and the value of maximum pressure drop set to zero.

Now that K_2' has been determined, an ESFF performance can be estimated. As noted earlier, the optimum value of applied field for ESFF performance is between 2.5 and 3.0 kV. Assume a value of 2.75 kV and enter that value for item 5 in the menu.

Now compute the maximum pressure drop for an ESFF baghouse by pressing * and RETURN. Note that the resulting value is significantly lower than the maximum pressure drop of the conventional baghouse. This indicates a potential savings in operating costs for an ESFF baghouse compared to a conventional baghouse. To determine whether or not this is true, return to the Main Menu by pressing ** followed by RETURN.

Before the capital and operating costs can be calculated, some preliminary information about the baghouse must be entered into the program. From the Main Menu choose menu option 2. The menu shown in Figure 5-9 will appear on the screen. Assume that the default value for Gas Temperature is adequate as well as the Expected Baghouse Life. Notice that the program has carried over the values of Air-to-Cloth Ratio and Applied Field from the performance modelling subroutine. Also, the average pressure drop as computed by the modelling subroutine has been entered here, so these values do not need to be changed. The remaining inputs (6 through 12) affect the

```
**********************************************************************
Pulse Jet Performance Model
**********************************************************************
 1 Residual Pressure Drop                              1.97   in H2O
 2 Inlet Dust Concentration                            0.31   lb/ft3
 3 Time between Cleaning Cycles                        1.000  min
 4 Air to Cloth Ratio                                  2.07   ft/min
 5 Applied Field                                       0.00   KV
 6 Specific Resistance Coefficient (K2)                0.00   dP/VW
 7 Maximum Pressure Drop                              10.0    in H2O

Enter the number of the item you want to change or enter
 * to perform calculations or enter ** to exit from this
subroutine.*

Conventional Pulse Jet Filter

Specific Resistance Coefficient =  6.03   dP/VW

Do you want a hardcopy y
```

Figure 5-8. The program will compute K_2 based on ΔP_r and ΔP_{max} (units of K_2 are inches H_2O ft · min/lb).

```
**********************************************************************
FABRIC FILTER COST INPUT
**********************************************************************
 1 Gas Temperature                                  302      F
 2 Expected Baghouse Life                            20      yrs
 3 Air to Cloth Ratio                                 2.074  ft/min
 4 Average Pressure Drop                              1.89   in H2O
 5 Applied Field                                      2.75   KV
 6 Cost of Fabric                                     4.65   $/m2
 7 Bag Life                                           4.0    yrs
 8 Labor Rate                                      $14.00    /hr
 9 Material Overhead Fraction                         0.100
10 Fan Load Factor                                    0.800
11 Scheduled Bag Replacement Time                     0      min/ft2
12 Unscheduled Bag Replacement Time                   1      min/ft2

Enter the number of the item you want to change or enter
* to exit from this routine
```

Figure 5-9. Input menu for baghouse design, operating, and cost data.

operating cost of the plant. Assume that all of these values are adequate but remember that they can be changed if necessary. Since no changes are needed from any of the menu parameters, return to the Main Menu by pressing * and RETURN.

Now the cost of a new ESFF baghouse can be computed by selecting option 4. When this routine is executed, the screen will clear and the results of the cost calculations will be presented as shown in Figure 5-10. The program lists all of the capital and operating costs as well as the Net Present Value of the baghouse. To compare this cost to that of a conventional pulse-jet filter, generate another set of costs. To do this, return to the Main Menu and execute Option 2 again. Change the average pressure drop to the value that was calculated above in the model routine for the conventional pulse jet case and set the value of Applied Field to 0 kV. Return to the Main Menu once again and exercise Option 4. The program will now compute the capital, operating, and NPV costs for a conventional filter. Note that when the Applied Field is 0 kV, the cost of ESFF hardware shown in the printout is 0.

This concludes the demonstration of how to use the PULSEJET program to estimate the performance and cost of both a conventional and an ESFF baghouse. All of the parameters necessary to estimate the cost can be entered via Options 1 and 2. Alternatively, if modelling calculations are necessary, the program will compute the design parameters necessary for cost estimation.

In the case of an ESFF retrofit to an existing baghouse, the procedure is similar, but a brief description is in order. The object of an ESFF retrofit is to reduce the pressure drop across the baghouse while maintaining the same air-to-cloth ratio, thereby reducing the cost of running the induced draft fan. Therefore, to evaluate the benefit of an ESFF retrofit, the reduction in pressure drop must be known. This can be determined with the aid of the Pulse-Jet Performance Model, Main Menu Option 3.

For example, assume that the manager of the hypothetical plant discussed earlier wants to evaluate the economic feasibility of retrofitting the existing, conventional baghouse with ESFF. Recall that the new ESFF baghouse considered above operates at the same air-to-cloth ratio as the existing, conventional baghouse but with a lower pressure drop. By retrofitting the

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
FABRIC FILTER COST SUMMARY
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Collector & Supports                    $ 8.96E+004
ESFF Hardware                           $ 4.65E+003
Ducting & Supports                      $ 3.97E+003
Ash Removal System                      $ 8.08E+004
Insulation                              $ 1.93E+004
Ash Pond                                $ 1.32E+004
ID Fan                                  $ 3.05E+003
Miscellaneous                           $ 2.28E+005
Total Field Cost.....................................$ 4.43E+005
Engineering                             $ 5.06E+004
Contingency                             $ 8.86E+004
Turn-key Cost........................................$ 5.82E+005
Operating Labor                         $ 5.92E+004
Maintenance Labor and Materials         $ 4.88E+004
Cost of Electricity                     $ 1.74E+003
Annual Cost of Bags and Cages           $ 1.01E+004
Net Present Value....................................$ 1.51E+006

Do you want a hardcopy y
```

Figure 5-10. The PULSEJET program prints a list of capital cost items, operating cost items, and net present value for new baghouses.

existing baghouse with ESFF, the two baghouses should perform identically. Therefore, to determine the cost of the ESFF retrofit, use the Baghouse Data Entry subroutine (Main Menu Option 3) to specify the expected average pressure drop, air-to-cloth ratio, and applied field. Return to the Main Menu and exercise Option 5. As with Main Menu Option 4, there is no input required in this subroutine; the results are calculated and printed on the screen, as in Figure 5-11.

To review the use of the retrofit cost routine, use the performance model or data from an existing pulse-jet ESFF baghouse to determine the air-to-cloth ratio, average pressure drop, and applied field. Enter these parameters into the Baghouse Data Entry subroutine and call Main Menu Option 5. In this sense Options 4 and 5 from the Main Menu are the same.

One last item to note about the Main Menu is Option number 6; "Change Cost Adjustment Factors." This routine is for specifying the adjustments to costs as described in Section 4.3. The menu for this routine is shown in Figure 5-12 and its operation is identical to the operation of Main Menu Options 1 and 2.

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
ESFF Retrofit Cost Analysis
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Collector & Supports                  $ 0.00E+000
ESFF Hardware                         $ 4.65E+003
Ducting & Supports                    $ 0.00E+000
Ash Removal System                    $ 0.00E+000
Insulation                            $ 0.00E+000
Ash Pond                              $ 0.00E+000
ID Fan                                $ 0.00E+000
Miscellaneous                         $ 4.95E+003
Total Field Cost.....................................$ 9.60E+003
Engineering                           $ 5.49E+002
Contingency                           $ 1.92E+003
Turn-key Cost........................................$ 1.21E+004
Operating Labor                       $ 0.00E+000
Maintenance Labor and Materials       $ 0.00E+000

Annual Operating Cost Savings $  4.77E+001
Savings/Investment Ratio :  0.035
Warning : Payback Period cannot be computed

Do you want a hardcopy y
```

Figure 5-11. The printout for a retrofit cost analysis includes the capital cost of ESFF hardware, the annual savings in operating cost, the savings/ investment ratio, and the payback period.

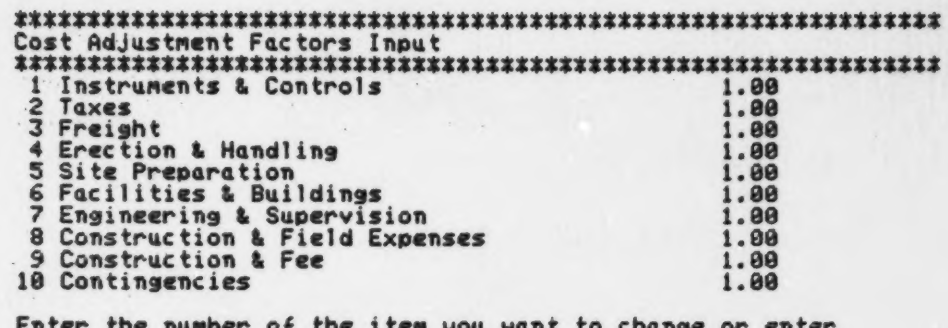
****
Cost Adjustment Factors Input
****
1 Instruments & Controls 1.00
2 Taxes 1.00
3 Freight 1.00
4 Erection & Handling 1.00
5 Site Preparation 1.00
6 Facilities & Buildings 1.00
7 Engineering & Supervision 1.00
8 Construction & Field Expenses 1.00
9 Construction & Fee 1.00
10 Contingencies 1.00
Enter the number of the item you want to change or enter
* to exit from this routine

Figure 5-12. The cost adjustment factors can be changed to reflect the complexity or simplicity of equipment installation.

6. REFERENCES

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APPENDIX A

CONVENTIONAL PULSE-JET MODELS

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CONVENTIONAL PULSE-JET MODELS

Because of the difficulties of using data from different sources taken under widely different conditions and with very different equipment, it is not possible to apply a single model to predict the pressure drop in a conventional pulse-jet filter. The purpose of this section is to describe the models presented in the literature in order to show what factors are expected to be of importance in conventional pulse-jet filters.

The two empirical models for pressure drop in pulse-jet filters illustrate qualitative effects. Dennis and Silverman[1] find that the average pressure drop for constant velocity filtration is primarily affected by the reservoir pressure, the inlet loading concentration, and the filtration time. Leith and First[2] found that reservoir pressure, filter loading, and face velocity are the major parameters affecting the maximum pressure drop across the filter. They found that the velocity raised to the 2.5 power had a strong affect on the pressure drop. The dependence on the reservoir pressure was P_j^{-2} and $P_j^{-1.4}$ by Dennis and Silverman, and Leith and First, respectively. Thus reservoir pressure was first found empirically to have an important effect on the pressure drop.

As previously discussed, Dennis et al.[3,4] attempted to theoretically predict P_e in terms of system variables. Using a combination of theoretical and empirical equations they found that the pressure rise time affects the effective residual pressure drop quite significantly. To relate the rise time to normally measured operating variables, they found

$$d(P)/dt = (kP_jA_j(T_j)^{.5}(P_b/V_b\rho_b) \; ; \qquad \text{(A-1)}$$

and empirically correlating their data they show

$$P_e = 615V(d(P)/dt)^{-1.13} \qquad \text{(A-2)}$$

TABLE A-1. MAJOR ASSUMPTIONS OF THE MODELS

Dennis and coworkers[3 4]

- 100 percent cleaning
- Distinguishes between cake structure of redeposited dust and freshly deposited dust
- Rise time important variable
- Empirical correlation of rise time with reservoir pressure

Leith and Ellenbecker[5]

- Cleaning efficiency a function of pressure drop
- No difference between cake structure of redeposited dust and freshly deposited dust
- Reverse pressure drop important variable
- Empirical correlation of static pressure with reservoir pressure

TABLE A-2. HOW TO TEST MODELS

Dennis and coworkers[3 4]

- Correlate (P_e) with dP/dt
- Test $dP/dt \propto P_j$
- Variables needed:

  (P_E), P_j, $d(P)/dt$, A_j, T_j, P_b, V_b, ρ_b, W_o, V, W, P

Leith and Ellenbecker[5]

- Test $\alpha \propto (P_S - P)$
- Correlate P_S with P_j
- Variables needed:

  P_S, P_j, P, ε, α, β, W_o, V, W_j, P_r

where

P_j = pulse reservoir pressure

A_j = nozzle cross-sectional area

T_j = absolute cleaning gas temperature

P_b = bag maximum static pressure

V_b = maximum bag volume

ρ_b = gas density

$d(P)/dt$ = rise time during cleaning pulse.

The constant k was experimentally developed for coal fly ash filtered with wool and polyester felts. This expression has not been tested widely either for the system for which it was derived or for other systems.

Leith and Ellenbecker[5] take a very different approach in developing a pressure drop model for conventional fabric filters. This approach may be of use in the future when more data have been found for the unknown parameters that they postulate in their model.

They assume a general expression similar to Equations 3 and 4 in Chapter 2

$$P = K_1 V + K_2 VW . \qquad (A-3)$$

However, they assume that the loading on the filter, W, is not equal to the dust that enters the filter, $W_o = C_{in}Vt$. They attempt to account for the fabric cleaning by defining ε as the fraction of the inlet dust that is removed from the filter and deposited in the hopper by each cleaning pulse. Therefore at steady state

$$W = W_o/\varepsilon . \qquad (A-4)$$

Furthermore to account for the dust that is redeposited on the filter after the cleaning pulse has finished they use

$$\varepsilon = \alpha \cdot \beta \qquad (A-5)$$

where α is the total fraction of inlet dust that is removed from the filter fabric by the cleaning pulse and β is the fraction of the removed dust α that falls to the hopper and is consequently removed from the system. They postulate that the fraction α is proportional to the applied removal force and that the removal force is given in terms of a reverse pressure drop. They define the reverse pressure drop as

$$PR = (P_s - P) \tag{A-6}$$

where P_s is the maximum static pressure supplied to the bag by the cleaning pulse. Thus, they postulate

$$\alpha = K_3(P_s - P) - K_4 \tag{A-7}$$

Combining equations A-3, A-4, and A-7 one can solve the resulting quadratic equation for P to give

$$P = \frac{(P_s - K_4/K_3 + K_1V)}{2} - \frac{\sqrt{(P_s - K_4/K_3 - K_1V)^2 - 4(W_o/\beta)V(K_2/K_3)}}{2} \tag{A-8}$$

Using limited data for their system they find that P_s is given by

$$P_s = P_j^{0.6} \tag{A-9}$$

Thus, reservoir pressure is important in this model because it is related to the maximum static bag pressure, and the bag static pressure is in turn related to the force that removes the dust. However, in order to use this model it is necessary to have data to evaluate the constants K_1, K_2, K_3, and K_4. Leith and Ellenbecker[6] assume that K_1 can be taken from the clean fabric, although the residual drag would be more appropriate, and that the ratio K_4/K_3 is negligible. Thus a set of data is needed to find the ratio K_2/K_3 and the constant β in order to apply this model. This model has not been generally tested and thus it is not recommended for use at the present time.

Table A-1 lists the assumptions made in the two different studies. Table A-2 lists the critical variables and equations that need to be measured and tested to improve and validate the models.

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APPENDIX B
Complete Listing of the Tektronix Version
of the PULSEJET Program

```
lis■■■
100 REM ****   ESFF Pulse Jet Cost/Performance Models   ****
110 REM Version 1.0 by A. S. Viner  1 Nov. 1982
120 J$="**********************************************************"
130 DIM C1(21),C2(14),C3(7),P(21),R(20),F(13),Z(16),A(10),M1(7)
140 DIM U$(4),E$(20),O$(20),G$(2)
150 HOME
160 PAGE
170 GOSUB 2110
180 GOSUB 2610
190 GOSUB 3200
200 GOSUB 3260
210 GOSUB 3500
220 GOSUB 3850
230 GOSUB 3900
240 GOSUB 4170
250 GOSUB 4220
260 PRINT "     DATE : ";
270 INPUT E$
280 FOR I=1 TO 16
290 Z(I)=0
300 NEXT I
310 M=0
320 O$=" "
330 PRINT
340 PRINT "DO YOU WANT ENGLISH OR METRIC UNITS (E OR M) ";
350 INPUT X$
360 U$=X$
370 IF POS("EeMm",U$,1)=0 THEN 340
380 HOME
390 PAGE
400 PRINT
410 PRINT
420 PRINT
430 GOSUB 2110
```

```
440 PRINT
450 PRINT "                    1. Enter Plant Data"
460 PRINT
470 PRINT "                    2. Enter Baghouse Data"
480 PRINT
490 PRINT "                    3. Estimate Pulse Jet Performance"
500 PRINT
510 PRINT "                    4. Calculate Costs for a New Baghouse"
520 PRINT
530 PRINT "                    5. Calculate Costs for ESFF retrofit"
540 PRINT
550 PRINT "                    6. Change Cost Adjustment Factors"
560 PRINT
570 PRINT "                    7. HELP"
580 PRINT
590 PRINT "                    8. END"
600 PRINT
610 PRINT
620 PRINT
630 PRINT "              Which option would you like to run (1-8) ";
640 INPUT O1
650 IF O1<1 OR O1>8 THEN 380
660 GOSUB O1 OF 690,1070,5110,4450,6100,1380,2310,680
670 GO TO 380
680 END
690 REM PLANT INPUT ROUTINE
700 IF U$<>"E" AND U$<>"e" THEN 720
710 GOSUB 1810
720 HOME
730 PAGE
740 PRINT
750 PRINT "Plant name ";
760 INPUT O$
770 HOME
780 PAGE
```

```
790 PRINT J$
800 PRINT "Data for Plant ";O$
810 PRINT J$
820 FOR J=1 TO 21
830 PRINT USING "2dxs":J
840 X$=SEG(P$,1+(J-1)*54,54)
850 PRINT USING X$:P(J);
860 X$=SEG(C$,1+M*147+(J-1)*7,7)
870 PRINT X$
880 NEXT J
890 GOSUB 2220
900 IF X$="*" THEN 980
910 IF X<1 OR X>21 THEN 890
920 PRINT
930 X$=SEG(P$,1+(X-1)*54,54)
940 PRINT USING X$:P(X);
950 PRINT " New value = ";
960 INPUT P(X)
970 GO TO 770
980 GOSUB 6580
990 GOSUB 2150
1000 IF M<>1 THEN 1020
1010 GOSUB 1810
1020 PRINT "DOES PLANT HAVE AN FGD SYSTEM FOR SO2 CONTROL (Y OR N) ";
1030 INPUT X$
1040 G$=SEG(X$,1,1)
1050 GOSUB 5000
1060 RETURN
1070 IF U$<>"E" AND U$<>"e" THEN 1100
1080 GOSUB 1910
1090 F(1)=(F(1)+40)*(9/5)-40
1100 HOME
1110 PAGE
1120 PRINT J$
1130 PRINT "FABRIC FILTER COST INPUT"
```

```
1140 PRINT J$
1150 FOR J=1 TO 12
1160 PRINT USING "2dxs":J
1170 X$=SEG(F$,1+(J-1)*56,56)
1180 PRINT USING X$:F(J);
1190 X$=SEG(D$,1+M*91+(J-1)*7,7)
1200 PRINT X$
1210 NEXT J
1220 GOSUB 2220
1230 IF X$="*" THEN 1310
1240 IF X<1 OR X>12 THEN 1220
1250 PRINT
1260 X$=SEG(F$,1+(X-1)*56,56)
1270 PRINT USING X$:F(X);
1280 PRINT " New value = ";
1290 INPUT F(X)
1300 GO TO 1100
1310 GOSUB 6580
1320 IF M<>1 THEN 1350
1330 GOSUB 1910
1340 F(1)=(F(1)+40)*(5/9)-40
1350 M1(4)=F(3)
1360 M1(5)=F(5)
1370 RETURN
1380 HOME
1390 PAGE
1400 PRINT J$
1410 PRINT "Cost Adjustment Factors Input"
1420 PRINT J$
1430 FOR J=1 TO 10
1440 PRINT USING "2dxs":J
1450 X$=SEG(A$,1+(J-1)*54,54)
1460 PRINT USING X$:A(J);
1470 NEXT J
1480 GOSUB 2220
```

```
1490 IF X$="*" THEN 1570
1500 IF X<1 OR X>10 THEN 1480
1510 PRINT
1520 X$=SEG(A$,1+(X-1)*54,54)
1530 PRINT USING X$:A(X);
1540 PRINT " New value = ";
1550 INPUT A(X)
1560 GO TO 1380
1570 GOSUB 6580
1580 RETURN
1590 REM *** Variable Initialization ***
1600 Z(1)=0.8*P(20)*10000000/P(13)
1610 IF INT(P(12))<=0 THEN 1630
1620 Z(1)=P(12)
1630 Z(2)=P(2)/100
1640 Z(3)=760-0.026*P(5)*3.281
1650 Z(4)=P(6)/100
1660 Z(5)=P(3)/230.6
1670 Z(6)=0
1680 Z(7)=100000/0.454*1/P(10)*P(1)/P(13)
1690 Z(6)=17.1*(P(15)/12+P(16)/4-P(17)/32+P(18)/32)*(1+P(14))
1700 Z(6)=Z(6)*760/(760-0.026*P(5)*3.281)
1710 Z(6)=Z(6)*Z(7)*0.3048↑3
1720 Z(8)=0
1730 IF INT(P(11))<=0 THEN 1750
1740 Z(8)=P(11)
1750 Z(9)=(1-P(4)/Z(1))*Z(1)*P(1)/P(10)*0.36
1760 Z(10)=F(13)*215/P(3)
1770 Z(11)=F(6)*215/P(3)
1780 IF Z(8)>0 THEN 1800
1790 Z(8)=Z(6)*((F(1)+273)/273)*(Z(3)-F(4)*10/13.6)/Z(3)
1800 RETURN
1810 REM UNITS CONVERSION
1820 FOR J=1 TO 21
1830 P(J)=P(J)*C1(J)
```

```
1840 C1(J)=1/C1(J)
1850 NEXT J
1860 IF M=1 THEN 1890
1870 M=1
1880 RETURN
1890 M=0
1900 RETURN
1910 REM Units CONVERSION
1920 FOR J=1 TO 13
1930 F(J)=F(J)*C2(J)
1940 C2(J)=1/C2(J)
1950 NEXT J
1960 IF M=1 THEN 1990
1970 M=1
1980 RETURN
1990 M=0
2000 RETURN
2010 REM Units Conversion
2020 FOR J=1 TO 7
2030 M1(J)=M1(J)*C3(J)
2040 C3(J)=1/C3(J)
2050 NEXT J
2060 IF M=1 THEN 2090
2070 M=1
2080 RETURN
2090 M=0
2100 RETURN
2110 PRINT J$
2120 PRINT "Pulse Jet Cost and Performance Models - Main Menu"
2130 PRINT J$
2140 RETURN
2150 REM  DISPLAY PLANT NAME ON SCREEN
2160 HOME
2170 PAGE
2180 PRINT J$
```

```
2190 PRINT "Plant : ";O$
2200 PRINT J$
2210 RETURN
2220 PRINT
2230 PRINT "Enter the number of the item you want to change or enter"
2240 PRINT "* to exit from this routine ";
2250 INPUT X$
2260 X=0
2270 X1=ASC(X$)
2280 IF X1<48 OR X1>57 THEN 2300
2290 X=VAL(X$)
2300 RETURN
2310 REM Instructions
2320 HOME
2330 PAGE
2340 PRINT
2350 PRINT "**********  HELP  **********"
2360 PRINT
2370 PRINT "     The screen which you just saw listed eight options"
2380 PRINT "which are available to you.  To execute any one of these "
2390 PRINT "options press a number between 1 and 8 followed by the "
2400 PRINT "RETURN key.  The program will execute the subroutine(s)"
2410 PRINT "which corresponds to that option number.  When that routine"
2420 PRINT "has been completed the program will return to the Main "
2430 PRINT "Menu.  The order in which the options are selected does not"
2440 PRINT "matter.  You can execute any of the subroutines any number"
2450 PRINT "of times."
2460 PRINT
2470 PRINT "     The data input options (1 and 2) and the Performance"
2480 PRI "Modeling option also present you with menus.  In these menus"
2490 PRINT "you are presented with a list of parameters and their "
2500 PRINT "values.  To change one of the values, enter its ID number "
2510 PRINT "(the number in the left-hand column) followed by RETURN."
2520 PRINT "Enter the new value for that parameter followed by RETURN."
2530 PRINT "The screen will be rewritten with the new value."
```

```
2540 PRINT
2550 PRINT "     For complete instructions consult the PULSEJET users"
2560 PRINT "documentation."
2570 PRINT
2580 PRINT "Press RETURN to continue ";
2590 INPUT X$
2600 RETURN
2610 REM
2620 REM PLANT DATA INITIALIZATION
2630 REM
2640 DIM P$(1512),C$(294)
2650 P$=""
2660 FOR I=1 TO 21
2670 READ X$
2680 P$=P$&X$
2690 NEXT I
2700 DATA """Boiler Size                                        ""3d.2dX S"
2710 DATA """Capacity Factor                                     ""2D.D  S"
2720 DATA """Chem. Eng. Plant Cost Index                        ""4D.D    S"
2730 DATA """Emission Limit                                    ""5D.DXX   S"
2740 DATA """Plant Altitude                                     ""4DXXXX  S"
2750 DATA """Effective Annual Discount Rate                       ""2D.2DxS"
2760 DATA """Cost of Electricity                                  ""2D.2DxS"
2770 DATA """Contingency as Percent of Field Cost                 ""2D.DxxS"
2780 DATA """Engineering as Percent of Field Cost                 ""2D.DxxS"
2790 DATA """Steam Cycle Efficiency                               ""2D.DxxS"
2800 DATA """Gas Flow Rate                                      ""4DXXXX  S"
2810 DATA """Boiler Emissions                                    ""3D.DXX S"
2820 DATA """Coal Heating Value                                 ""5dXXXX   s"
2830 DATA """Fraction Excess Air                                   ""D.2DxS"
2840 DATA """Percent Carbon in Coal                                ""2D.2DxS"
2850 DATA """Percent Hydrogen in Coal                              ""2D.2DxS"
2860 DATA """Percent Oxygen in Coal                                ""2D.2DxS"
2870 DATA """Percent Sulfur in Coal                                ""2D.2DxS"
2880 DATA """Percent Nitrogen in Coal                              ""2D.2DxS"
```

```
2890 DATA """Percent Ash in Coal                                    ""2D.2DxS"
2900 DATA """Percent Water in Coal                                  ""2D.2DxS"
2910 FOR I=1 TO 21
2920 C1(I)=1
2930 NEXT I
2940 C1(1)=3.41
2950 C1(4)=0.002326
2960 C1(5)=3.281
2970 C1(11)=2.119
2980 C1(12)=0.232
2990 C1(13)=0.43
3000 FOR I=0 TO 1
3010 FOR J=1 TO 21
3020 X$=""
3030 NEXT J
3040 NEXT I
3050 B$="        "
3060 Z$="%       "
3070 C$="MJ/s    "&B$
3080 C$=C$&B$
3090 C$=C$&"ng/J    m       /yr     mil/kwh%        %       %       acms    "
3100 C$=C$&"ng/J    kJ/kg           "
3110 FOR I=1 TO 7
3120 C$=C$&Z$
3130 NEXT I
3140 C$=C$&"MBtu/hr                 lb/MBtuft       /yr     mil/kwh%        "
3150 C$=C$&"%       %       Kacfm   lb/MBtuBtu/lb           "
3160 FOR I=1 TO 7
3170 C$=C$&Z$
3180 NEXT I
3190 RETURN
3200 FOR I=1 TO 21
3210 READ P(I)
3220 NEXT I
3230 DATA 1,70,310,43,0,10,30,20,20,85,0,0,23240,0.25,60,5.4,11.2,0.6
```

```
3240 DATA 1.6,7.6,13.6
3250 RETURN
3260 DIM R$(1224)
3270 R$=""
3280 FOR I=1 TO 17
3290 READ X$
3300 R$=R$&X$
3310 NEXT I
3320 DATA """Collector & Supports                    $""2E              "
3330 DATA """ESFF Hardware                           $""2E              "
3340 DATA """Ducting & Supports                      $""2E              "
3350 DATA """Ash Removal System                      $""2E              "
3360 DATA """Insulation                              $""2E              "
3370 DATA """Ash Pond                                $""2E              "
3380 DATA """ID Fan                                  $""2E              "
3390 DATA """Miscellaneous                           $""2E              "
3400 DATA """Total Field Cost.....................................$""2E"
3410 DATA """Engineering                             $""2E              "
3420 DATA """Contingency                             $""2E              "
3430 DATA """Turn-key Cost.....................................$""2E"
3440 DATA """Operating Labor                         $""2E              "
3450 DATA """Maintenance Labor and Materials         $""2E              "
3460 DATA """Cost of Electricity                     $""2E              "
3470 DATA """Annual Cost of Bags and Cages           $""2E              "
3480 DATA """Net Present Value.....................................$""2E"
3490 RETURN
3500 REM
3510 REM FABRIC FILTER DATA INITIALIZATION
3520 REM
3530 DIM F$(864),D$(182)
3540 F$=""
3550 FOR I=1 TO 13
3560 READ X$
3570 F$=F$&X$
3580 NEXT I
```

```
3590 DATA """Gas Temperature                                        ""3DXXXX S"
3600 DATA """Expected Baghouse Life                                 ""2Dxxxx S"
3610 DATA """Air to Cloth Ratio                                      ""D.3D S"
3620 DATA """Average Pressure Drop                                  ""2D.2DX S"
3630 DATA """Applied Field                                          ""2d.2dx s"
3640 DATA """Cost of Fabric                                         ""2d.2dx s"
3650 DATA """Bag Life                                               ""2D.Dxx S"
3660 DATA """Labor Rate                                            $""2D.2Dx S"
3670 DATA """Material Overhead Fraction                             ""D.3D S"
3680 DATA """Fan Load Factor                                        ""D.3D S"
3690 DATA """Scheduled Bag Replacement Time                         ""2Dxxxx S"
3700 DATA """Unscheduled Bag Replacement Time                       ""2Dxxxx S"
3710 DATA """Fraction of Unscheduled Bag Replacements     ""D.3D    S "
3720 FOR I=1 TO 13
3730 C2(I)=1
3740 NEXT I
3750 D$=" C       yrs     m/min  cm H2O KV      $/m2   yrs     /hr    "
3760 D$=D$&"                 min/m2 min/m2        "
3770 D$=D$&" F       yrs     ft/min in H2O KV      $/ft2 "
3780 D$=D$&" yrs     /hr                  min/ft2min/ft2       "
3790 C2(4)=0.3937
3800 C2(3)=3.281
3810 C2(6)=0.093
3820 C2(11)=0.093
3830 C2(12)=0.093
3840 RETURN
3850 FOR I=1 TO 13
3860 READ F(I)
3870 NEXT I
3880 DATA 150,20,0.632,7.5,0,50,4,14,0.1,0.8,2,7,0.05
3890 RETURN
3900 REM
3910 REM Pulse Jet Model Initialization
3920 REM
3930 DIM M$(392),W$(98)
```

```
3940 M$=""
3950 FOR I=1 TO 7
3960 READ X$
3970 M$=M$&X$
3980 NEXT I
3990 DATA """Residual Pressure Drop                                  ""2D.2dXS"
4000 DATA """Inlet Dust Concentration                               ""2D.2dxS"
4010 DATA """Time between Cleaning Cycles                           ""2D.3D S"
4020 DATA """Air to Cloth Ratio                                     ""2D.2DXS"
4030 DATA """Applied Field                                          ""2d.2dxs"
4040 DATA """Specific Resistance Coefficient (K2)                   ""2d.2dxs"
4050 DATA """Maximum Pressure Drop                                  ""2D.DxxS"
4060 FOR I=1 TO 7
4070 C3(I)=1
4080 NEXT I
4090 C3(1)=0.3937
4100 C3(2)=0.062
4110 C3(4)=3.281
4120 C3(6)=5.987
4130 C3(7)=0.3937
4140 W$=" cm H2O kg/m3  min    m/min  KV    Nmin/gm cm H2O in H2O"
4150 W$=W$&" lb/ft3 min    ft/min KV     dP/VW  in H2O"
4160 RETURN
4170 FOR I=1 TO 7
4180 READ M1(I)
4190 NEXT I
4200 DATA 5,5,1,0.632,0,3,0
4210 RETURN
4220 REM
4230 REM Cost Adjustment Factor Initialization
4240 REM
4250 DIM A$(540)
4260 A$=""
4270 FOR I=1 TO 10
4280 READ X$
```

```
4290 A$=A$&X$
4300 NEXT I
4310 DATA """Instruments & Controls                    "" D.2D   "
4320 DATA """Taxes                                     "" d.2d   "
4330 DATA """Freight                                   "" d.2d   "
4340 DATA """Erection & Handling                       "" D.2D   "
4350 DATA """Site Preparation                          "" D.2D   "
4360 DATA """Facilities & Buildings                    ""D.2D    "
4370 DATA """Engineering & Supervision                 ""D.2D    "
4380 DATA """Construction & Field Expenses             "" D.2D   "
4390 DATA """Construction & Fee                        "" D.2D   "
4400 DATA """Contingencies                             "" D.2D   "
4410 FOR I=1 TO 10
4420 A(I)=1
4430 NEXT I
4440 RETURN
4450 REM
4460 REM FABRIC FILTER COST SUBROUTINE
4470 REM
4480 GOSUB 1590
4490 GOSUB 4970
4500 Z(12)=Z(8)*60/F(3)
4510 Z(14)=Z(12)/1.46
4520 Z(15)=(Z(12)<5110)*4.49*Z(12)↑0.835
4530 Z(15)=Z(15)+(Z(12)>5110 AND Z(12)<16722)*1.752*Z(12)↑0.9461
4540 Z(15)=Z(15)+(Z(12)>16722)*1.04*Z(12)
4550 R(1)=(5370+81.8*Z(12))*Z(5)+(1+F(9))*F(6)*Z(15)
4560 R(2)=0
4570 IF F(5)=0 THEN 4600
4580 R(2)=6.4*Z(14)+1.2*4*Z(14)+24+1.2*2*SQR(Z(14))
4590 R(2)=(R(2)+1835*(1+INT(7.85E-4*Z(14))))*P(3)/310
4600 R(3)=1100+64.8*Z(8)+15.24*(-5.77+177*1.128*0.3137*Z(8)↑0.5)
4610 R(3)=R(3)*Z(5)
4620 R(4)=69000*Z(5)
4630 R(5)=(4910+25.8*Z(12))*Z(5)
```

```
4640 R(6)=P2*1.395*1.2*P(3)/148.2
4650 R(7)=(2600+0.2494*Z(8))*Z(5)
4660 R(8)=0
4670 FOR I=1 TO 7
4680 R(8)=R(8)+R(I)
4690 NEXT I
4700 R(9)=R(8)
4710 R(8)=R(8)*(0.1*A(1)+0.03*A(2)+0.05*A(3))
4720 Z(13)=R(9)+R(8)
4730 R(8)=R(8)+(0.22+0.5*A(4)+0.01*A(5)+0.02*A(6))*Z(13)
4740 R(9)=R(9)+R(8)
4750 R(10)=P(9)/100*A(7)*Z(13)
4760 R(11)=Z(13)*(P(8)/100*A(8)+0.1*A(9)+0.02+0.03*A(10))
4770 R(12)=R(9)+R(10)+R(11)
4780 R(13)=8760/8*(1.5+2.4E-4*Z(12))*1.8*1.334*F(8)
4790 R(14)=8760/8*(1.5+2.4E-4*Z(12))*1.8*1.1*F(8)
4800 R(15)=(F(10)*8760*0.182*Z(8)*F(4)+66.74*Z(15))*Z(2)*P(7)/1000
4810 R(15)=R(15)+8760*Z(14)*0.39/0.6*F(5)/1000*Z(2)*P(7)/1000
4820 R(16)=(1+F(9))*F(6)*Z(15)/F(7)
4830 R(17)=R(13)+R(14)+R(15)+R(16)
4840 R(17)=R(9)+R(17)*(1.1↑F(2)-1)/(LOG(1.1)*1.1↑F(2))
4850 HOME
4860 PAGE
4870 K$="++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
4880 PRINT K$
4890 PRINT "FABRIC FILTER COST SUMMARY"
4900 PRINT K$
4910 FOR I=1 TO 17
4920 X$=SEG(R$,1+(I-1)*52,52)
4930 PRINT USING X$:R(I)
4940 NEXT I
4950 GOSUB 6580
4960 RETURN
4970 REM
4980 REM POND SIZE, POND COST SUBROUTINE
```

```
4990 REM
5000 IF G$="Y" OR G$="y" THEN 5040
5010 P3=0.08267*Z(9)*Z(2)
5020 P2=13648*P3↑0.583
5030 RETURN
5040 F1=0.7*Z(9)
5050 P3=0.08267*(Z(9)+F1)*Z(2)
5060 P1=13648*P3↑0.583
5070 F2=0.08267*F1*Z(2)
5080 F3=13648*F2↑0.583
5090 P2=P1-F3
5100 RETURN
5110 REM
5120 REM Pulse Jet Performance Model Calculations
5130 REM
5140 IF U$<>"E" AND U$<>"e" THEN 5160
5150 GOSUB 2010
5160 H$=SEG(W$,M*49+1,7)
5170 I$=SEG(W$,M*49+35,7)
5180 HOME
5190 PAGE
5200 PRINT J$
5210 PRINT "Pulse Jet Performance Model"
5220 PRINT J$
5230 FOR J=1 TO 7
5240 PRINT USING "2dxs":J
5250 X$=SEG(M$,1+(J-1)*56,56)
5260 PRINT USING X$:M1(J);
5270 X$=SEG(W$,1+M*49+(J-1)*7,7)
5280 PRINT X$
5290 NEXT J
5300 PRINT
5310 PRINT "Enter the number of the item you want to change or enter"
5320 PRINT " * to perform calculations or enter ** to exit from this"
5330 PRINT "subroutine.";
```

```
5340 INPUT X$
5350 X=0
5360 X1=ASC(X$)
5370 IF X1<48 OR X1>57 THEN 5390
5380 X=VAL(X$)
5390 IF X$<>"**" THEN 5450
5400 IF M<>1 THEN 5420
5410 GOSUB 2010
5420 F(3)=M1(4)
5430 F(5)=M1(5)
5440 RETURN
5450 IF X$="*" THEN 5580
5460 IF X<1 OR X>7 THEN 5300
5470 PRINT
5480 X$=SEG(M$,1+(X-1)*56,56)
5490 PRINT USING X$:M1(X);
5500 PRINT " New value = ";
5510 INPUT M1(X)
5520 IF X<6 THEN 5180
5530 IF X=7 THEN 5560
5540 M1(7)=0
5550 GO TO 5180
5560 M1(6)=0
5570 GO TO 5180
5580 IF M1(5)>0 THEN 5830
5590 PRINT
5600 PRINT "Conventional Pulse Jet Filter"
5610 IF M1(6)=0 THEN 5730
5620 D1=M1(1)+M1(6)*M1(2)*M1(3)*M1(4)↑2
5630 D2=(D1+M1(1))/2
5640 Z(16)=D2
5650 F(4)=Z(16)*M/C2(4)
5660 PRINT
5670 PRINT USING """Maximum Pressure Drop = ""2d.2dxs":D1
5680 PRINT H$
```

```
5690 PRINT USING """Average Pressure Drop = ""2d.2dxs":D2
5700 PRINT H$
5710 GOSUB 6580
5720 GO TO 5180
5730 K2=(M1(7)-M1(1))/(M1(2)*M1(3)*M1(4)↑2)
5740 M1(6)=K2
5750 Z(16)=(M1(7)+M1(1))/2
5760 F(4)=Z(16)*M/C2(4)
5770 M1(7)=0
5780 PRINT
5790 PRINT USING """Specific Resistance Coefficient = ""2d.2dxs":K2
5800 PRINT I$
5810 GOSUB 6580
5820 GO TO 5180
5830 PRINT
5840 PRINT "ESFF Pulse Jet Filter"
5850 IF M1(6)=0 THEN 6030
5860 P1=0.58*M1(1)
5870 P2=(M1(5)<0.75)*(1-0.63*M1(5)+0.21*M1(5)↑2-0.024*M1(5)↑3)
5880 P2=P2+(M1(5)=>0.75)*0.77*EXP(-0.25*M1(5))
5890 Z(16)=M1(1)+M1(6)*M1(2)*M1(3)*M1(4)↑2/2
5900 P3=P1*P2*Z(16)
5910 P4=(P3+P1)/2
5920 F(4)=P4*M/C2(4)
5930 PRINT
5940 PRINT USING """ESFF Residual Pressure Drop = ""2d.2dxs":P1
5950 PRINT H$
5960 PRINT USING """ESFF Average Pressure Drop  = ""2d.2dxs":P4
5970 PRINT H$
5980 PRINT USING """ESFF Maximum Pressure Drop  = ""2d.2dxs":P3
5990 PRINT H$
6000 PRINT USING """Pressure Drop Ratio (PDR)   = ""d.3d":P2
6010 GOSUB 6580
6020 GO TO 5180
6030 K2=(M1(7)-M1(1))/(M1(2)*M1(3)*M1(4)↑2)
```

```
6040 PRINT
6050 PRINT USING """Specific Resistance Coefficient = ""2d.2dxs":K2
6060 PRINT I$
6070 M1(6)=K2
6080 M1(7)=0
6090 GO TO 5860
6100 REM
6110 REM ESFF Retrofit Cost SUBROUTINE
6120 REM
6130 GOSUB 1590
6140 Z(12)=Z(8)*60/F(3)
6150 Z(14)=Z(12)/1.46
6160 FOR I=1 TO 17
6170 R(I)=0
6180 NEXT I
6190 R(2)=6.4*Z(14)+1.2*4*Z(14)+24+1.2*2*SQR(Z(14))
6200 R(2)=(R(2)+1835*(1+INT(7.85E-4*Z(14))))*P(3)/310
6210 R(8)=R(2)
6220 R(9)=R(8)
6230 R(8)=R(8)*(0.1*A(1)+0.03*A(2)+0.05*A(3))
6240 Z(13)=R(9)+R(8)
6250 R(8)=R(8)+(0.22+0.5*A(4)+0.01*A(5)+0.02*A(6))*Z(13)
6260 R(9)=R(9)+R(8)
6270 R(10)=0.1*A(7)*Z(13)
6280 R(11)=Z(13)*(0.2*A(8)+0.1*A(9)+0.02+0.03*A(10))
6290 R(12)=R(9)+R(10)+R(11)
6300 R(15)=8760*(0.182*Z(8)*(Z(16)-F(4))*F(10)-0.39/0.6*F(5)*Z(14)/1000)
6310 R(15)=R(15)*Z(2)*P(7)/1000
6320 B0=LOG(1+P(6)/100)
6330 B1=(EXP(F(2)*B0)-1)/(B0*EXP(F(2)*B0))
6340 S1=R(15)*B1
6350 R(17)=S1/R(12)
6360 P4=0
6370 IF B0*R(12)/R(15)>1 THEN 6390
6380 P4=-LOG(1-B0*R(12)/R(15))/B0
```

```
6390 HOME
6400 PAGE
6410 PRINT K$
6420 PRINT "ESFF Retrofit Cost Analysis"
6430 PRINT K$
6440 FOR I=1 TO 14
6450 X$=SEG(R$,1+(I-1)*52,52)
6460 PRINT USING X$:R(I)
6470 NEXT I
6480 PRINT
6490 PRINT USING """Annual Operating Cost Savings $ ""2e":R(15)
6500 PRINT USING """Savings/Investment Ratio : ""2d.3d":R(17)
6510 IF P4=0 THEN 6550
6520 PRINT USING """Payback Period : ""3d.2dxs                    ":P4
6530 PRINT "years"
6540 GOSUB 6580
6550 PRINT "Warning : Payback Period cannot be computed "
6560 GOSUB 6580
6570 RETURN
6580 PRINT
6590 PRINT "Do you want a hardcopy ";
6600 INPUT X$
6610 IF POS("YyNn",X$,1)=0 THEN 6590
6620 IF POS("Yy",X$,1)=0 THEN 6640
6630 COPY
6640 RETURN
```

APPENDIX C

Cost Estimates for Industrial Coal-Fired Boiler, Pulse-Jet Baghouse Systems

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Cost Estimates for Industrial Coal-Fired Boiler, Pulse-Jet Baghouse Systems

One of the tasks of this project was to verify the models used for predicting capital costs. The lack of published data on these costs led to the conclusion that cost quotes would have to be obtained. Mr. Gary Greiner of ETS, Incorporated, of Roanoke, Virginia, is a veteran in the field of industrial scale baghouse systems. Mr. Greiner was hired as a consultant with the task of obtaining reliable estimates of capital costs for pulse-jet baghouses. His report is included in the following pages.

COST ESTIMATES FOR INDUSTRIAL COAL-FIRED BOILER, PULSE-JET BAGHOUSE SYSTEMS

PURPOSE:

To provide cost estimates for pulse-jet baghouse systems applied to industrial coal-fired boiler plants. Information to be used as check against a model being developed at RTI.

REQUIRED OUTPUT:

Cost estimates in $/ft.^{2} cloth for three representative sizes of systems.

APPROACH:

System sizes were chosen representative of small, medium and large boiler plants; 55,000 ACFM, 180,000 ACFM and 350,000 ACFM were used.

Several vendors were contacted and interviewed to obtain: design G/C ratios; module sizes available for this application; bag sizes being used or proposed; and flange-to-flange hardware costs.

From these interviews and prior ETS data, the following information was developed.

ASSUMPTIONS:

All systems are modular in design and capable of module isolation for off-line cleaning.

Costs are for hardware components listed below. Engineering, installation, system components outside the flange-to-flange baghouse are not included. The ash handling system is not included, as this is seldom supplied by the baghouse OEM and no good cost estimates were obtained.

INCLUDED COMPONENTS:

- Module housings complete with pulse system
- Woven Glass bags and cages
- Inlet and outlet manifolds
- Inlet and outlet dampers
- Insulation and flashing
- Hopper heaters
- Baghouse controls
- Structural supports and access

TYPICAL SYSTEM ARRANGEMENT & COST

SYSTEM ACFM	55,000	180,000	350,000
# Modules	4	10	14
Gross G/C	4.0	3.91	3.96
Net G/C	5.2	4.34	4.63
# Bags/Module	190	210	210
Bag Size	6"Ø x12' Lg.	6"Ø x14' Lg.	6"Ø x19' Lg.
Cloth/Module	3500	4600	6300 ft.^{2}
Total Gross Ft.^{2}	13,750	46,000	88,200
Total Net Ft.^{2}	10,500	41,400	75,600
Cost $/Ft.^{2}	$24	$20	$17

ADDITIONAL COMMENTS:

- This market continues to be very competitive and prices have not increased over the past few years. If the market opens up, these prices could increase substantially.
- Specific job quotes will normally have a range of 2/1 if 5-7 quotes are obtained.
- 19' long bags are only being offered by a few OEM's, but they have been the past leaders in this market.
- The cost VS size curve tends to be very flat once a module and bag size are chosen since most hardware costs have a per bag relationship.